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A Study of Wi-Fi RFID Tags in Citywide Wireless Networks

How well do Wi-Fi RFID tags work in outdoor Wi-Fi networks and is it possible to build commercial services based on Wi-Fi RFID tags in citywide wireless networks?

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Problem Description

How well do Wi-Fi based active RFID tags work in citywide wireless networks like Trådløse Trondheim? Which limitations does this technology imply? Is it possible to develop commercial services based on Wi-Fi RFID tags?

The assignment should include surveying the technology, suggesting possible applications, testing related to possible applications and considerations on
business potentials.

Assignment given: 18. January 2007
Supervisor: Yuming Jiang, ITEM

Preface

This report is the result of my Master's thesis carried out at the Department of Telematics at The Norwegian University of Science and Technology (NTNU).

I would like to thank my main supervisor, Professor Yuming Jiang for giving me helpful guidelines on how to approach the problem statement and for suggesting the submission of an extended abstract to the IEEE ISWCS 2007 conference.

I would also thank my co-supervisor and managing director in Trådløse Trondheim AS, Thomas Jelle for all the helpful information and motivation during the process.

Håvard Holje deserves thanks for helping me with the GeoPos tag requests. John Krogstie, Marius Bjørge and Lars Martin Kristensen also deserves thanks for providing the GeoTrans Java class used when converting the GeoPos coordinates.

Finally, I would like to thank my friends and fellow students at the TAPAS office for great days and valuable discussions.

Trondheim, June 15th 2007

Henrik Ljøgodt Moen

Abstract

Active Radio Frequency Identification (RFID) tags that comply with IEEE 802.11 standards are currently used within indoor Real-Time Location Systems (RTLS) in several niche markets. With the rapid deployment of citywide wireless networks, outdoor Location-Based Services (LBS) have become an important research area. Such services are believed to have a considerable business potential in citywide wireless networks. Wi-Fi RFID tags can be used to take advantage of such a potential. However, very limited testing has been carried out in order to examine the performance of the Wi-Fi RFID technology in outdoor environments.

Wireless Trondheim is one of the first citywide wireless networks in Europe. In this Master's thesis, the possibilities for building commercial services based on Wi-Fi RFID tags in Wireless Trondheim are examined. Three potential services, which can utilize such tags are also proposed. In order to verify the reality of a possible implementation of these services, five test scenarios are carried out with Wi-Fi RFID tags within Wireless Trondheim.

The location-based solution in Wireless Trondheim has explicitly no support for determining location in outdoor environments. Nevertheless, testing is important to identify how well the Wi-Fi RFID technology perform in such environments. The results presented in this report point out several limitations with this technology in the citywide wireless network. Considerable variations in the location accuracy and precision are revealed. Problems with delayed location updates when traveling between adjacent coverage zones are also discovered. These limitations constrain the commercial services that can be based on Wi-Fi RFID tags in Wireless Trondheim. Currently, on-demand services with limited requirements to the accuracy of the computed location are supported to some extent. However, real-time services, which require a high degree of location accuracy are not supported with the location-based solution in this citywide wireless network. The described limitations should be improved in order to achieve an acceptable performance for LBS. Such improvements are also essential in order to determine the business potential of LBS in in a citywide wireless network like Wireless Trondheim.

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List of Abbreviations

API	Application Programming Interface
BSS	Basic Service Set
CCA	Clear Channel Assessment
CDP	Cisco Discovery Protocol
DFS	Dynamic Frequency Selection
DHCP	Dynamic Host Configuration Protocol
DSSS	Direct Sequence Spread Spectrum
EIRP	Equivalent Isotopic Radiated Power
EPC	Electronic Product Code
EUREF89	European Reference Frame 1989
GIS	Geographic Information System
GPS	Global Positioning System
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISO	International Standards Organization
LAN	Local Area Network
LBS	Location-Based Services
LLC	Logical Link Control
LWAPP	Light-Weight Access Point Protocol
MAC	Media Access Control

NFC	Near Field Communication
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open Systems Interconnection
RF	Radio Frequency
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
RTLS	Real-Time Location Systems
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
SSID	Service Set Identifier
TDoA	Time Difference of Arrival
TPC	Transmitter Power Control
UTM	Universal Transverse Mercator
WCS	Wireless Control System
WDS	Wireless Distribution System
WGS84	World Geodetic System
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
XML	Extended Markup Language

Chapter 1

Introduction

1.1 Motivation

The Radio Frequency Identification (RFID) technology is attracting considerable attention these days, in both research and business communities. Traditionally, this technology has been used within supply chain management, logistics and manufacturing. Such RFID systems are generally based on vendor specific solutions with proprietary readers.

The past five years, a new category of active RFID tags that comply with IEEE 802.11 standards, has been adopted in niche markets. These tags, known as Wi-Fi RFID tags, can be identified and located using regular Wi-Fi access points. These access points are inexpensive and easily available, resulting in cost-efficient solutions for Location-Based Services (LBS). Wi-Fi RFID tags are proven to work well in indoor wireless networks, especially in Real-Time Location Systems (RTLS) within hospitals and shopping centers. However, the rapid deployment of citywide wireless networks world wide enables potentials for using the Wi-Fi RFID technology in outdoor environments. There has been limited testing with Wi-Fi RFID tags outdoors, where the network characteristics can be very different.

Wireless Trondheim is the largest Wi-Fi deployment in Norway. Location-Based Services that utilize Wi-Fi RFID tags are believed to have a substantial business potential in this network. To consider this potential, surveying the performance of the Wi-Fi RFID technology is important. Thus, comprehensive testing of Wi-Fi RFID tags and their performance within the citywide wireless network is needed. The results of such testing will determine what kind of services that currently can be supported by Wi-Fi RFID tags.

1.2 Scope

RFID tags operate using different radio technologies and standards. In this Master's thesis, only active RFID tags complying with IEEE 802.11 standards are considered. The Wi-Fi RFID tags that are being tested to come from the Norwegian manufacturer Radionor Communications. However, these tags are currently not supported by the Cisco wireless infrastructure in Wireless Trondheim. Thus, the Cisco certified AeroScout T2 tags are used as an alternative.

Several error sources, which can affect the performance of the Wi-Fi RFID tags in the outdoor environment are described in this report. The degree of which they are believed to affect the test results are also identified. However, a detailed discussion of their impact on the tag performance is out of the scope of this report.

1.3 Methodology

The head goal with this Master's thesis is to identify whether Wi-Fi RFID tags can be used for commercial purposes in citywide wireless networks. This is investigated by performing a set of five test scenarios within Wireless Trondheim. In addition, suggestions are given on three possible applications than can utilize Wi-Fi active RFID tags. The reality in each of the proposed services is then discussed and verified based on the test results.

1.4 Reference Comments

Much of the Wi-Fi related information in this report is cited from Cisco Systems Inc. and AeroScout Inc. This is mainly because of the equipment currently used in the Wireless Trondheim deployment and the difficulties in getting relevant information from other sources. Chapter 3, Wireless Trondheim, is based on the initial document describing the project and several personal conversations with the Managing Director, Thomas Jelle. Listings in the References section marked with a star (*) are also available electronically.

1.5 Related work

1.5.1 Legoland

Legoland in Billund, Denmark is one of Europe's largest theme parks. The theme park runs a 65.000 m^2 802.11 wireless network. In 2004 a service utilizing Wi-Fi RFID tags to track children was introduced to the visitors in the theme park. A wristband with an AeroScout T2 Wi-Fi RFID tag is available for rent and can be attached to a child's arm. If the child is lost throughout the park, the parents can send a text message to the system, and get the location of their child. The system uses 34 proprietary AeroScout location receivers, which supports Time Difference of Arrival (TDoA) and triangulation. The system is capable of providing a positioning accuracy of 2 meters, with the tags transmitting every 8 seconds. The software solution is delivered by AeroScout and Kidspotter [19] [31] [42].

1.5.2 i-Safety

A test pilot similar to the Legoland system was also deployed in Yokohama, Japan in 2006. With participants like Nissan Motor Co. and NTT Communications, the main goal was to provide better safety for children on their way to and from school. In this deployment, the children used Wi-Fi RFID tags to alert parents and security personnel, when in danger. Existing Cisco Wi-Fi access points were used together with AeroScout T2 tags and special AeroScout software [28] [43].

1.5.3 Location Testing in Wireless Trondheim

In the spring of 2006, two location tests with a regular laptop computer were carried out at Solsiden in Trondheim. The results of the tests show that there are considerable variations in the location accuracy outdoors. In the first test, ten distinct location within the coverage area were chosen, with six of these locations being outdoors. The average error distance was computed to approximately 30 meters. In the second test, the laptop was placed at a static location for 20 minutes. Each minute during this period, the location was monitored. The average error distance was computed to approximately 50 meters in the second test [47].

1.6 Report Outline

This report is divided into eight chapters and an additional appendix. Technological background information for the understanding of citywide wireless networks and Wi-Fi RFID tags is given in Chapter 2. The Wireless Trondheim deployment is described in Chapter 3. In Chapter 4, three services that can utilize Wi-Fi RFID tags in a citywide wireless network are proposed. Chapter 5 describes the testing equipment and five test scenarios. The main test results are presented in Chapter 6. In Chapter 7 a discussion on the reality of currently implementing these services in Wireless Trondheim is given. Finally, a conclusion is given in Chapter 8, together with guidelines for future work.

Chapter 2

Technological Background

This chapter presents general technological background for citywide wireless networks, their architecture and common standards. The RFID technology is also presented, with the focus on Wi-Fi RFID tags. In addition, different positioning techniques that are used in Wi-Fi based location systems are given.

2.1 WLAN Architecture

2.1.1 Traditional WLAN

A Wireless Local Area Network (WLAN) can be designed and deployed with different levels of complexity. Basically, a traditional WLAN architecture consists of four main components. These components are depicted in Figure 2.1.

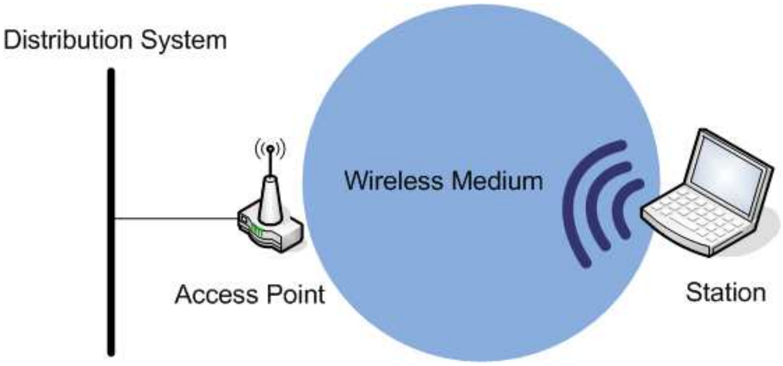
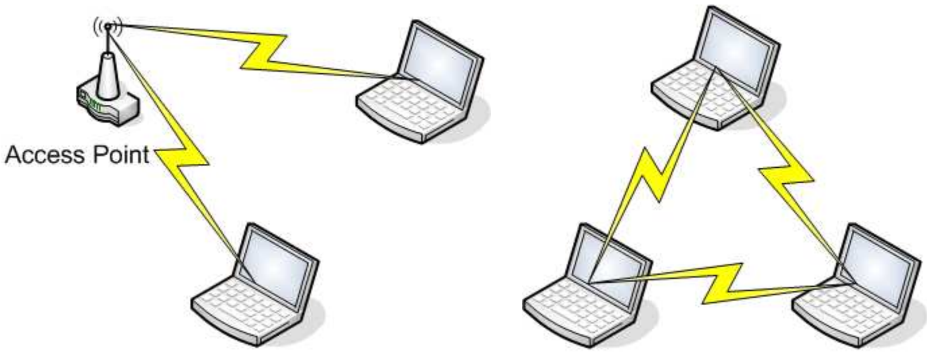


Figure 2.1: Components in a traditional WLAN

The purpose of a WLAN is to transfer information wirelessly between stations. These stations are typically laptops or other mobile terminals that are equipped with a wireless interface. The communication is done through a wireless medium. The stations communicate with access points, which are connected to a wired distribution system or backbone network. Hence, the access points perform a wireless-to-wired bridging function [13].

A group of stations that communicate with each other is called a Basic Service Set (BSS). An access point and all the stations that are able to communicate with each other within the coverage area of the access point, is said to be in an Infrastructure Basic Service Set.

Two stations can also communicate directly with each other, without using an access point. Several stations communicating directly together, form an ad-hoc network or an Independent Basic Service Set (IBSS). Figure 2.2 illustrates how the stations communicate with each other in the independent and infrastructure BSSs.



(a) Infrastructure Basic Service Set

(b) Independent Basic Service Set (IBSS)

Figure 2.2: Communication between stations in Infrastructure BSS and IBSS

2.1.2 Citywide Wireless Networks

In large WLAN deployments, such as citywide wireless networks, several access points are often cooperating with each other to serve a certain area. In such systems, access point controllers are used as additional components in the architecture. In these architectures, much of the functionality is moved from the access point to the controller. Light-weight access points communicate with the controllers using special tunneling protocols.

A citywide wireless network requires a large number of access points to cover the entire area. Connecting all these access points directly to the wired distribution network is costly. Thus, wireless links are often used to interconnect access points. In such interconnections, at least one access point is wired to the backbone network. This access point functions as a bridge for the other access points in the interconnection. If there are multiple paths to backbone network, the network is referred to as a wireless mesh. This is illustrated in figure 2.3. In outdoor deployments, additional external high-gain antennas are often connected to the access points in order to cover a larger area [23].

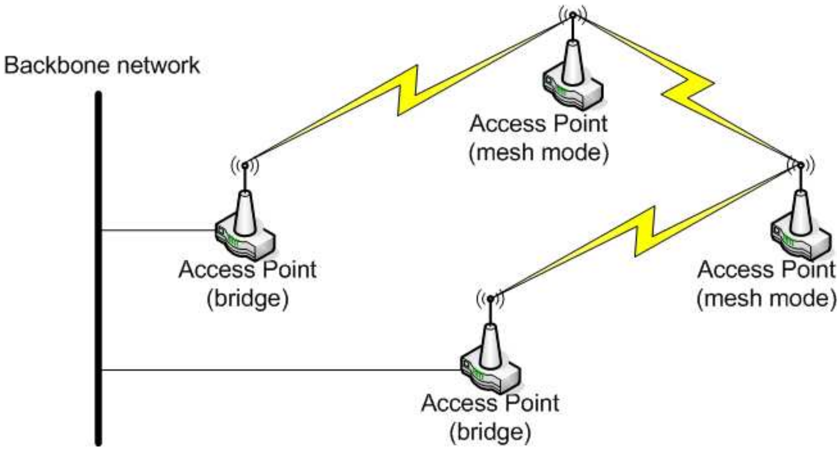


Figure 2.3: A wireless mesh network. Two access points are interconnected with wireless links and multiple paths are available to the backbone network.

2.1.2.1 The Cisco Unified Wireless Network Solution

The Cisco Unified Wireless Network Solution is an example of a WLAN architecture utilizing controllers and light-weight access points. This solution is illustrated in Figure 2.4.

The infrastructure elements in this architecture include the Cisco Aironet Lightweight Access Points and the Cisco Wireless LAN Controllers. Additional elements are the Cisco Wireless Location Appliance, a location server, which computes, collects and stores location data about stations in the network and the Cisco Wireless Control System (WCS). The latter is used to manage and control the wireless network. The access points communicate with the controllers using the Light-Weight Access Point Protocol (LWAPP). Communication between the location server and the controllers are done with the Simple Network Management Protocol (SNMP) polling. The WCS server and third party location based applications communicate with the location server using an Application Programming Interface (API) based on the Simple Object Access Protocol (SOAP) and the Extended Markup Language (XML).

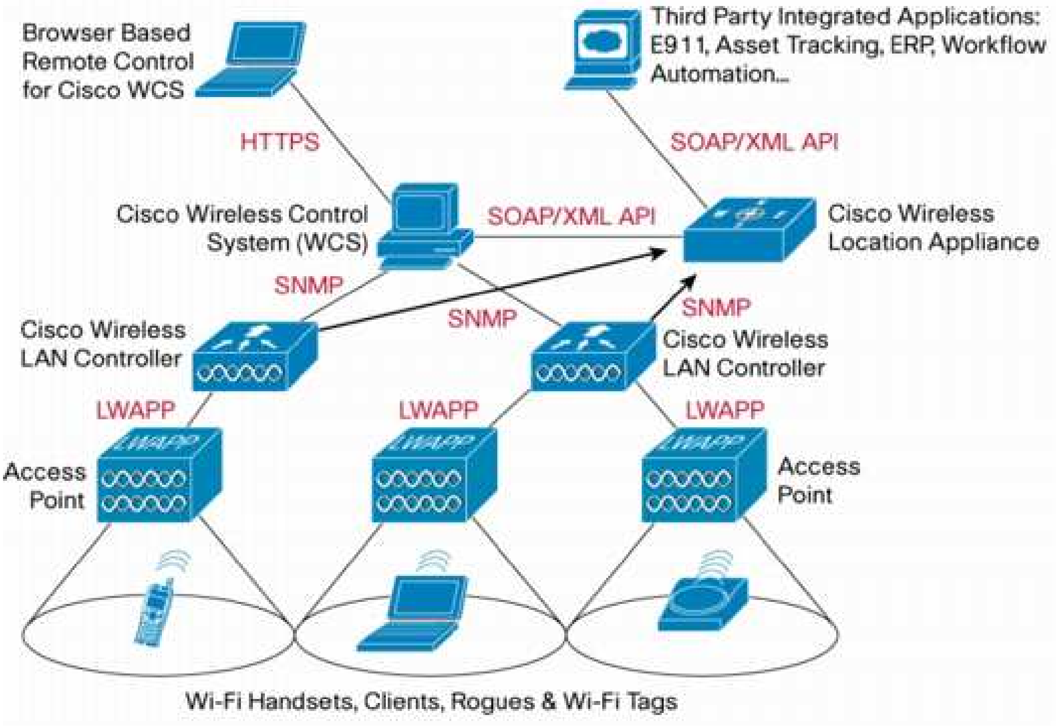


Figure 2.4: The Cisco Unified Wireless Network architecture, from [24]

2.2 WLAN Standards

In all data communication, standardized protocols are important for the interoperability among equipment from different vendors. The Institute of Electrical and Electronics Engineers (IEEE) has published a family of WLAN standards, known as IEEE 802.11. In addition, the non-profit organization the Wi-Fi Alliance is testing and certifying that 802.11 equipment work together. Thus, WLANs utilizing 802.11 standardized equipment are commonly referred to as Wi-Fi networks.

2.2.1 IEEE 802.11a, 802.11b and 802.11g

The 802.11 standards specify the physical layer and the Media Access Control (MAC) part of the data link layer. The Logical Link Control (LLC) part of the data link layer is equal to the other IEEE 802 specifications. Figure 2.5 shows the relationship between the 802.11 specifications and the Open Systems Interconnection (OSI) reference model.

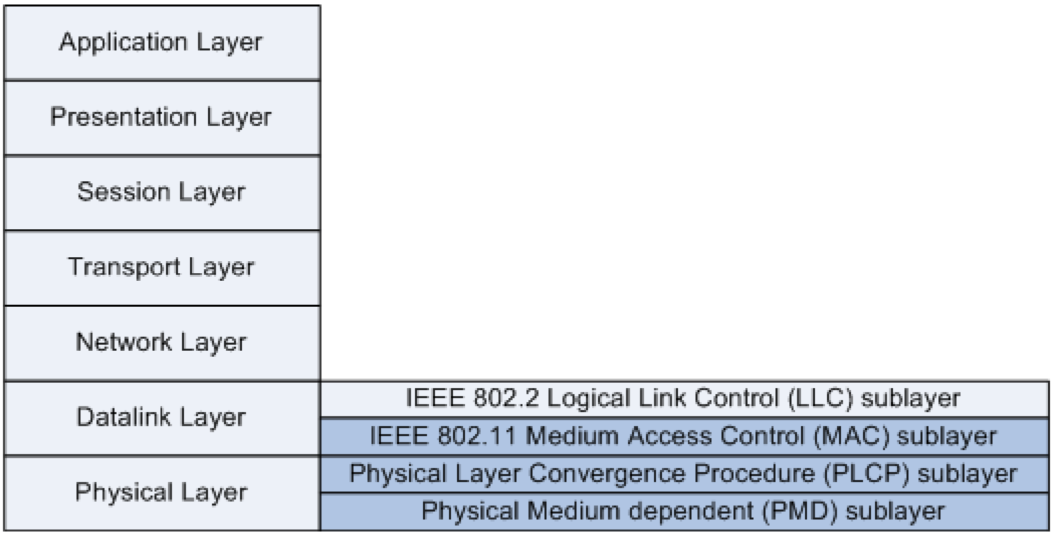


Figure 2.5: The relationship between the IEEE 802.11 and the OSI reference model

Table 2.1 shows the three standards that currently are widespread in use in mass market Wi-Fi equipment. Their specifications at the physical layer are different, and so is the capacity they can offer and the frequency band they utilize.

IEEE standard	*Max speed*	*Frequency band*	*Modulation*
802.11a	54 Mbps	5 GHz	OFDM
802.11b	11 Mbps	2.4 GHz	DSSS
802.11g	54 Mbps	2.4 GHz	OFDM

Table 2.1: Comparison of 802.11a/b/g physical layers

The 802.11b physical layer is based on the Direct Sequence Spread Spectrum (DSSS) modulation technique, which spreads the transmitted signal energy over a wider frequency band by multiplying the signal by a pseudorandom noise code. This standard uses the non-licensed 2.4 GHz frequency band, and can offer theoretical data rates up to 11 Mbps [13].

The 2.4 GHz frequency band is heavy utilized both by 802.11 stations and other equipment. Thus, the 802.11a is specified to operate in the 5 GHz unlicensed frequency band. 802.11a offers theoretical data rates up to 54 Mbps and its physical layer is based on Orthogonal Frequency Division Multiplexing (OFDM). OFDM divides the available bandwidth into several subchannels. The signal is transmitted using these subchannels in parallel and multiplexing data over the set of subchannels. OFDM is more adaptable to interference than other modulation techniques because the subchannels are selected orthogonally. Hence, OFDM is better suited for outdoor deployments [10] [13].

As with 802.11a, the 802.11g physical layer is based on OFDM and supports theoretical data rates up to 54 Mbps. However, 802.11g operates in the 2.4 GHz frequency band and also supports DSSS for backwards compatibility with 802.11b.

2.3 RFID

RFID is a technology for identification based on radio transponders. Basically, an RFID implementation consists of two components; a transponder tag and a reader or interrogator. The transponder tag emits messages readable by the RFID reader. These messages contain some sort of identification number, which uniquely identifies the tag [32] [48].

2.3.1 Transponder Tags

The RFID transponder tags can be divided into mainly two different types; active and passive tags. The main difference between the two types is their power source, size and transmission range. Both types of tags can use several different types of radios and frequency bands.

2.3.1.1 Passive Tags

A passive tag uses energy from the electromagnetic Radio Frequency (RF) field generated by the RFID reader to transmit its signal. The tag therefore relies on the RFID reader to get the needed transmission power. Thus, the transmission range is limited for passive tags and they must pass some sort of choke point to be identified. The passive tags are usually small in size and can be obtained at low costs. Figure 2.6 shows how a passive RFID tag is read.

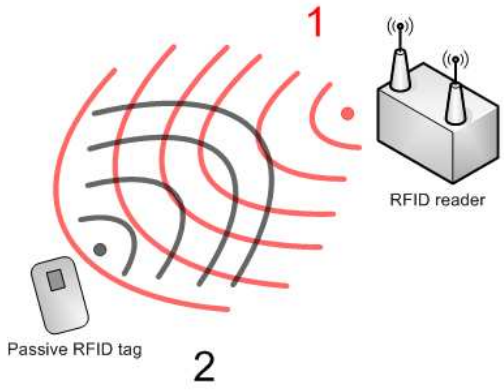


Figure 2.6: A passive RFID tag within the RF field of the reader

2.3.1.2 Active Tags

An active tag has an on-board battery or another direct power source. The term active relates to the tag's ability to transmit regardless of being in the RF field of a reader. The tag can either be configured to transmit its messages constantly by beaconing, or to transmit only when it is prompted to do so. Thus, active RFID tags are said to be either beaconing active RFID tags or transponder active RFID tags. Active RFID tags usually have a greater range because of the internal power source. Hence, such tags can be used in RTLS, which are described in a separate section in this chapter. Active RFID tags are usually more expensive than the passive tags, and have a larger size. Figure 2.7 shows the operation of an active RFID tag [25] [32].

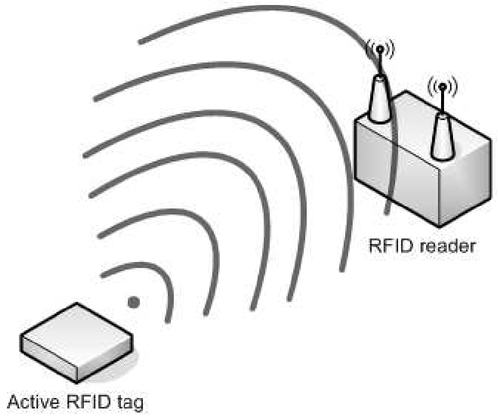


Figure 2.7: An active RFID tag transmitting to a reader

2.3.1.3 Semi-passive Tags

The benefits from the two types of tags described above can be utilized to form a semi-passive RFID tag. As with passive tags, the semi-passive tags require RF energy from the reader to transmit. However, an additional internal battery is used to power the tag's circuitry and additional sensors that monitor environmental conditions. Semi-passive RFID tags are therefore also known ass battery-assisted RFID tags [25] [37].

2.3.2 RFID Tag Applications

RFID tags enable several possible applications within identification and location tracking. Depending of the application requirements, RFID tag systems operate at different frequencies. While lower frequency systems are more power efficient when transmitting, high frequency systems usually have better transmission ranges. Many of the systems are proprietary solutions, where special RFID readers are used.

Table 2.2 shows some RFID tag applications and the frequency and tag type suitable for each application.

Frequency (band)	*Tag type*	*Application*
Low (9-135 kHz)	Passive	Animal tracking, vehicle immobilizers
High (13.553-15.567 MHz)	Passive	Access control, luggage control, biometrics
Amateur radio (430-440 MHz)	Active	Container and vehicle identification, proprietary RTLS
Ultra-high (860-930 MHz)	Passive	Supply chain management
Microwave (2.4-2.4835 GHz and 5.8 GHz)	Active and semi-passive	Open standard RTLS, electronic toll payment

Table 2.2: RFID tag applications with corresponding frequency bands, based on [8]

2.3.3 RFID Standards

The International Standards Organization (ISO) has developed several standards for automatic identification and item management using RFID. The ISO 14443 standard defines the radio interface and communication protocol for payment systems and contactless smart cards. Corresponding standards for supply chain management systems are defined in the ISO 18000 series of standards.

In addition to ISO, the non-profit organization EPCglobal has developed standards for identifying items in supply chains using RFID. The standardized Electronic Product Code (EPC) is an electronic bar code, which is used for this purpose. Items carrying RFID tags with EPC can be identified regardless of being within line of sight from a reader.

For active RFID tag systems, standardized communication protocols, such as Wi-Fi, ZigBee and Near Field Communication (NFC) are being used as alternatives to proprietary protocols [15].

2.4 Wi-Fi RFID Tag Systems

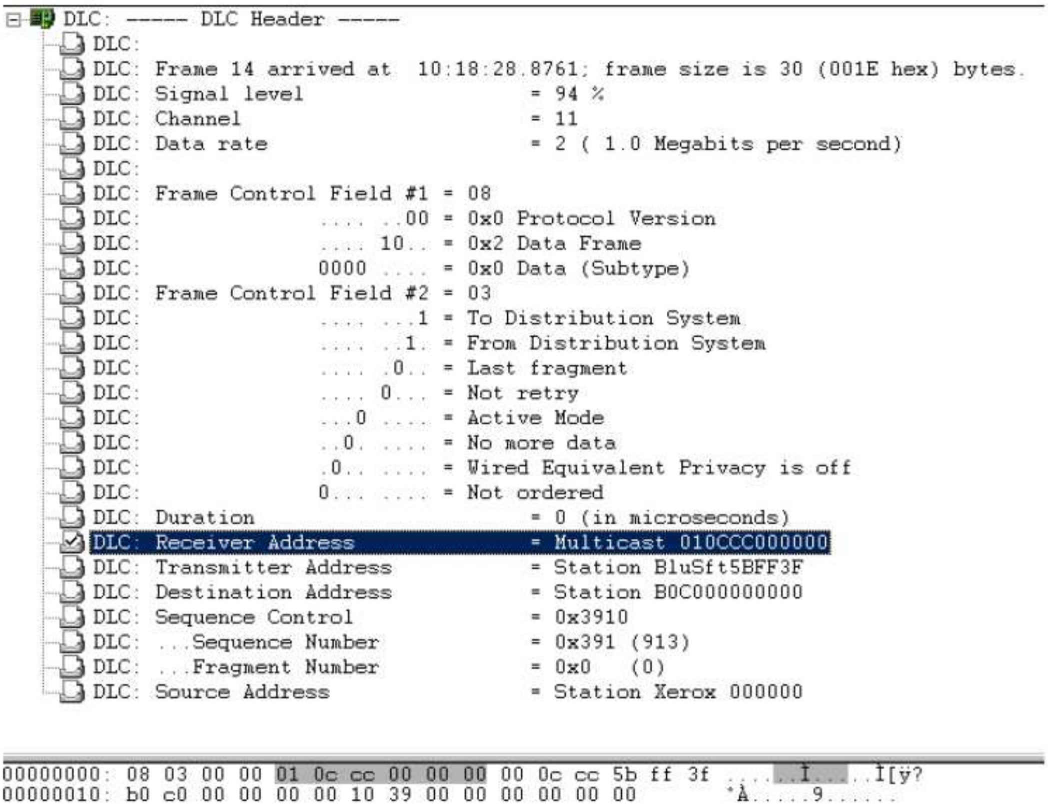
Wi-Fi RFID tags are active RFID tags that comply with IEEE 802.11 standards and protocols. These tags are designed to operate in the same frequency band as regular Wi-Fi equipment. Wi-Fi RFID tags can be uniquely identified by the MAC address, using standard Wi-Fi access points. Thus, no additional RFID readers have to be deployed. The main advantage is reduced costs and more rapid deployments in existing wireless networks.

There are mainly two types of Wi-Fi RFID tags. The first type consists of tags that associate with the network as normal stations. The second type does not associate with access points, but instead communicates using Layer 2 multicasts. Wi-Fi RFID tags come from manufacturers like AeroScout, PanGo, Ekahau and Radionor.

2.4.1 AeroScout T2 Tag

The AeroScout T2 tag is an example of a Wi-Fi RFID tag that uses Layer 2 multicasts in communication with the network. This tag has an IEEE 802.11b compliant transceiver, which is utilized to transmit a 30 byte 802.11 data frame at a preset beaconing interval. The frame can be sent on up to three preset channels and repeated several times with each transmission. Before each transmission, the tag initiates a Clear Channel Assessment (CCA) for 100 microseconds. Figure 2.8 shows the contents of such a multicast frame from a protocol analyzer trace.

The AeroScout T2 data frames are destined to a multicast receiver address. The



```
DLC: ----- DLC Header -----
  DLC:
  DLC: Frame 14 arrived at  10:18:28.8761; frame size is 30 (001E hex) bytes.
  DLC: Signal level                 = 94 %
  DLC: Channel                      = 11
  DLC: Data rate                    = 2 ( 1.0 Megabits per second)
  DLC:
  DLC: Frame Control Field #1 = 08
  DLC:              .... ..00 = 0x0 Protocol Version
  DLC:              .... 10.. = 0x2 Data Frame
  DLC:              0000 .... = 0x0 Data (Subtype)
  DLC: Frame Control Field #2 = 03
  DLC:              .... ...1 = To Distribution System
  DLC:              .... ..1. = From Distribution System
  DLC:              .... .0.. = Last fragment
  DLC:              .... 0... = Not retry
  DLC:              ...0 .... = Active Mode
  DLC:              ..0. .... = No more data
  DLC:              .0.. .... = Wired Equivalent Privacy is off
  DLC:              0... .... = Not ordered
  DLC: Duration                     = 0 (in microseconds)
  DLC: Receiver Address             = Multicast 010CCC000000
  DLC: Transmitter Address          = Station BluSft5BFF3F
  DLC: Destination Address          = Station B0C000000000
  DLC: Sequence Control             = 0x3910
  DLC: ...Sequence Number           = 0x391 (913)
  DLC: ...Fragment Number           = 0x0   (0)
  DLC: Source Address               = Station Xerox 000000

00000000: 08 03 00 00 01 0c cc 00 00 00 00 0c cc 5b ff 3f  ......Ì.....Ì[ÿ?
00000010: b0 c0 00 00 00 00 10 39 00 00 00 00 00 00        °À.....9......
```

Figure 2.8: Data frame from an AeroScout T2 tag, from [24]

address is 01:0c:cc:00:00:00, which is used by the Cisco Discovery Protocol (CDP). The tag is therefore compatible with any standard Cisco access point. Using the address fields in the data frame header, the frame can be destined within the IBSS or to the Wireless Distribution System (WDS). In this example, the latter is chosen. More information about the addressing of data frames can be found in Appendix E. The AeroScout T2 tag has an embedded motion sensor and can optionally be equipped with a temperature sensor and a call button. A table showing the estimated battery lifetime with different parameter configurations is found in Appendix B.

2.4.2 PanGo Locator LAN Tag V2

Unlike the AeroScout T2 tag, the PanGo Locator LAN tag fully associates and authenticates to the WLAN infrastructure. In the same way as a regular laptop computer or mobile terminal, the tag also acquires an IP address via DHCP. The tag also includes an embedded motion sensor and can transmit on up to 11 channels [24] [38]. More details about different Wi-Fi RFID tags are found in Appendix C.

2.5 RTLS

Wi-Fi RFID tags are commonly used in RTLS to track the location of valuable assets. Utilizing an existing Wi-Fi infrastructure, it is possible to monitor the assets throughout the wireless coverage area. This is achievable due to the use of active RFID tags, which do not have to pass close to a reader or interrogator to be located. However, an RTLS can only be as real-time as the currently last known location measurements. Several factors, such as the tag beaconing interval and the location server polling interval affect the real-time nature of an RTLS [25].

2.6 Wi-Fi Based Positioning

Wi-Fi RTLSs use different techniques for determining the location of a client or RFID tag. The location can be computed using signal strength or timing information, observed at a single or multiple access points. There are mainly four different location determination approaches that are used in Wi-Fi networks [25]. The approaches differ in which physical measurements they take into account, and how these are used in the location computation.

2.6.1 Closest Access Point

The most basic of the four location determination techniques, is to identify the location based on the access point that is closest to the client or RFID tag. This can be done by looking at the association between the client and the access point or by measuring signal strength. However, the closest access point method has a low degree of accuracy because an access point usually has a large coverage area [24].

2.6.2 Distance

A more advanced location determination technique is to compute the approximately distance between the client or RFID tag and one or more access points.

This technique is called lateration. The distance can be computed based on signal strength or timing information [16].

2.6.2.1 Received Signal Strength Indication

Signal strength is a measurement on how strongly a transmitted signal is being received at a particular distance from the transmitter. The signal strength varies with distance, obstacles and interfering RF signals. Multi path fading also affect the signal strength. In Wi-Fi networks, the signal strength is defined as Received Signal Strength Indication (RSSI). RADAR is a building-wide tracking system that uses RSSI to compute the location of wireless devices [6] [16].

There are no requirements for the accuracy and precision of RSSI values. RSSI is intended to be relative to the wireless chipset, and inconsistency among different vendors occurs [7]. RSSI can be measured both by the mobile station or the network infrastructure. When the former is used, the mobile station reports the signal strength of the transmissions it receives from the network. When the latter is used, the network infrastructure reports the signal strength at which it receives the transmissions from the mobile client. Access points in a specific deployment are usually from a single vendor, while the user equipment is from several different manufacturers. Thus, RSSI measurements at the network side are preferred in order to minimize inconsistency [25].

2.6.2.2 Time Difference of Arrival

Distance can also be calculated based on signal propagation time. Radio waves travel at a known speed through the wireless medium. Thus, if the time of transmission and time of signal arrival are known, the distance can be computed. Time Difference of Arrival (TDoA) is an example of such a technique. In TDoA, the location is computed based on the difference in time when the signal arrives at different base stations. TDoA is utilized for instance in proprietary AeroScout Location Receivers implementations, which often are used instead of, or in addition to standard Wi-Fi access points [17].

2.6.3 Angle

Instead of timing information, angles can be used to calculate the location. At each access point, the wireless signal arrives at a certain angle. By using geometric relationships between the angle of arrival at two access points, the estimated location can be computed [16] [25].

2.6.4 Triangulation and Trilateration

When the location is estimated based on angle measurements from three or more access points the method is referred to as triangulation. The signal strength or timing information from several access points can also be used together to form coverage circles and intersection points. If the distance from at least three different points can be computed, this technique is known as trilateration. With the use of algorithms, the tag's most likely location will be pointed based on the information from the different access points. The more access points that contribute in computing the location, the more likely it is to get an accurate approximation [16] [25].

2.6.5 Location Patterning

None of the above location determination techniques take into account signal propagation characteristics, such as reflection, attenuation and multi-path fading. However, with the location patterning technique, such characteristics of the actual wireless medium considered in the location computation. This location patterning technique requires extensive calibration, in order to record how the wireless signals propagate throughout the environment. During this calibration phase, RF characteristics and real world data regarding how obstacles affect the propagation are collected and pre-stored in a database. This information is then compared with real-time information from the access points to achieve a more accurate location approximation. The Cisco RF Fingerprinting is an example of method using the location patterning technique [24].

Chapter 3

Wireless Trondheim

Wireless Trondheim is the largest outdoor Wi-Fi deployment in Norway. This chapter gives an introduction to Wireless Trondheim and the motivation behind the project. The technologies used in the current deployment are also presented, together with future plans for technological solutions.

3.1 Motivation and Progress

The motivation behind the Wireless Trondheim project is to enable a citywide wireless network for research and development. The Norwegian University of Science and Technology (NTNU) took the initiative of starting the project in the summer of 2005. Several other partners have later joined the project. Currently, the partners are the municipality of Trondheim, the Sør-Trøndelag County Council, SpareBank 1 Midt-Norge, Adresseavisen and Trondheim Energiverk.

Wireless Trondheim opened in September 2006 and made Trondheim one of Europe's first wireless cities. At the same time, a private limited company was established under the name Trådløse Trondheim AS (Wireless Trondheim Ltd.). The core activity of the company is to provide Layer 2 access for multiple service providers. Each service provider is operating using their own Service Set Identifier (SSID), and is responsible for providing higher layer services for their users. Supporting mobility and positioning, the Wireless Trondheim network is intended for enabling context-aware services. Such services are believed to have substantial business potentials. The Wireless Trondheim network is currently available for students at NTNU and partner employees [29] [46].

Figure 3.1 shows the current coverage areas of Wireless Trondheim.

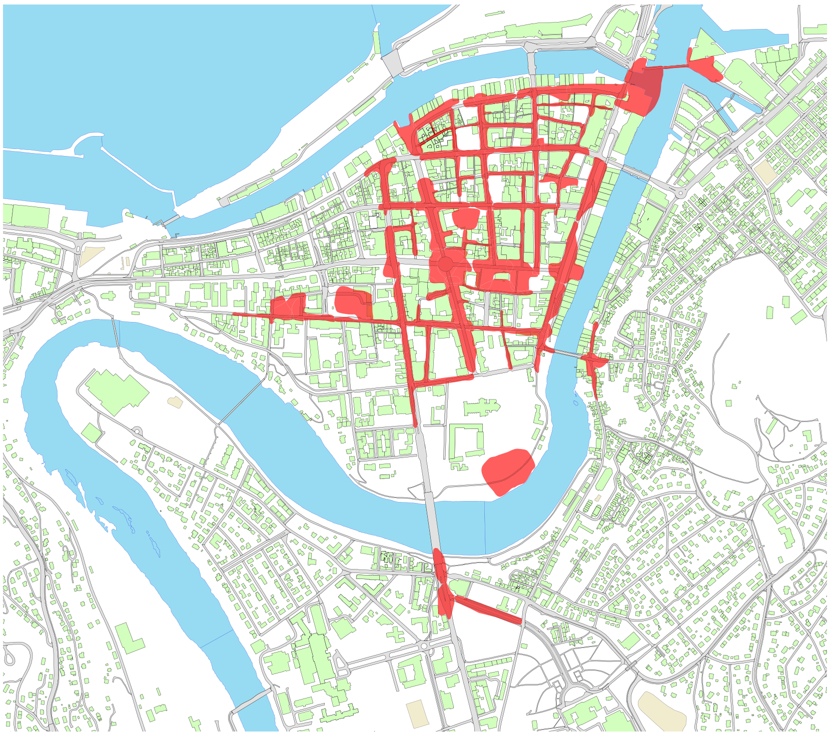


Figure 3.1: The Wireless Trondheim coverage areas in the scale 1:10 000. Red color indicates areas with at least 11 Mbps capacity. The figure is obtained from Trådløse Trondheim AS

3.2 Technology

The current deployment in Wireless Trondheim are based on Wi-Fi and utilizes the Cisco Unified Wireless Network infrastructure described in Chapter 2. More than 100 light-weight access points, two WLAN controllers, one location server and one server running the WCS software make up the LBS solution in Wireless Trondheim. The majority of these elements are connected to a fiber distribution system. However, not all access points are placed at locations where fiber is available. Some of the access points are wirelessly interconnected with a radio link to another access point, with the latter being connected to the distribution system. There are redundancy in some of the interconnections, but none of the access points have multiple hops to the distribution system. Thus, the Wireless Trondheim deployment is not a full mesh network.

The access points have both 802.11b/g and 802.11a radios. However, the latter is mostly used in the wireless interconnections between access points. There are also a couple of access points that support 802.11a towards the end users. The access points utilize high-gain external antennas to shape and control the coverage areas. The Norwegian Post and Telecommunications Authority (NPT) puts regulations on the maximum transmission effects these antennas can radiate, known as Equivalent Isotopic Radiated Power (EIRP). These regulations are 100 mW in the 2.4 GHz band, and between 200 mW and 4W in the 5 GHz band, depending on the channel and whether Transmitter Power Control (TPC) and Dynamic Frequency Selection (DFS) are implemented [40].

3.3 Future Plans

The current deployment is based on the Wi-Fi technology. Future plans are to utilize other wireless technologies to cover the entire city with wireless broadband access. The IEEE 802.16e, also known as mobile WiMAX, is a promising technology for this purpose. Support for inter-media roaming among different wireless technologies is also within the future plans [29].

Chapter 4

Wi-Fi RFID Tag Applications

Wi-Fi RFID tags have several applications within a citywide wireless network like Wireless Trondheim. In this chapter, a proposition is given on three services that can utilize Wi-Fi RFID tags in such an environment. These services and their requirements to performance of the tag and the location based network solution are presented with respect to a potential commercial implementation. Based on the test results presented in Chapter 5, the reality in each of the proposed services will be discussed in Chapter 7.

4.1 Location as a Service Enabler

Being able to pinpoint the location of an item in the network can enable a set of new services. LBS are services, which take the location of the user or mobile device into consideration [35]. A LBS is more than a plain positioning and navigation system like the Global Positioning System (GPS). The application of LBSs is not limited to providing the current location or guidelines for getting from one location to another.

However, location by its self is seldom sufficient in order to build value-added services for the end user. Additional information about the surrounding environment can be of importance in many applications. Services that adapt according to the current location, the people nearby or the accessible devices are said to be context-aware services [36]. Such services can make new business opportunities for a network provider. In addition, building services based on location information can give a sustainable competitive advantage for the business actors in the shared wireless network.

4.2 Proposed services

Wi-Fi RFID tags have a broad range of possible applications, such as tracking valuable assets and reporting sensor data. In this section, three commercial services that can utilize such tags are proposed. A brief motivation for each service is given, together with suggestions on how the service can be implemented.

4.2.1 City Bike Locator

There are currently 125 city bikes available for citizens and tourists in Trondheim [34]. Ten stations with electronically locked bike racks are deployed throughout the city center, and the majority of these stations are currently covered by Wireless Trondheim. The city bike stations are shown in Figure 4.1.

Figure 4.1: The City Bike stations in Trondheim, from [34]

For less than €30 a year, the bikes can be used freely throughout the city center. The bikes may be used for a maximum time of three hours before returning it at any of the ten bike racks. Enabling location information about the bikes can be valuable for both the users and the providers of this service.

The City Bike Locator service offers an easier way of finding an available bike. In this service, location information is collected from Wi-Fi RFID tags fixed to the bikes. The Wi-Fi infrastructure is utilized to monitor the bike locations. Location information about the bikes can enable the users to locate the nearest available city bike.

This service can be implemented with a simple web application, where the user can input their current location. Automatic location computing can also be supported, based on the location of the mobile device used to access the service. The service looks up the closest city bike rack with available bikes and presents this to the user. The distance to get there and s map showing the possible areas for returning the bike can also be included in this service. Figure 4.2 illustrates a possible user interface for the City Bike Locator service.

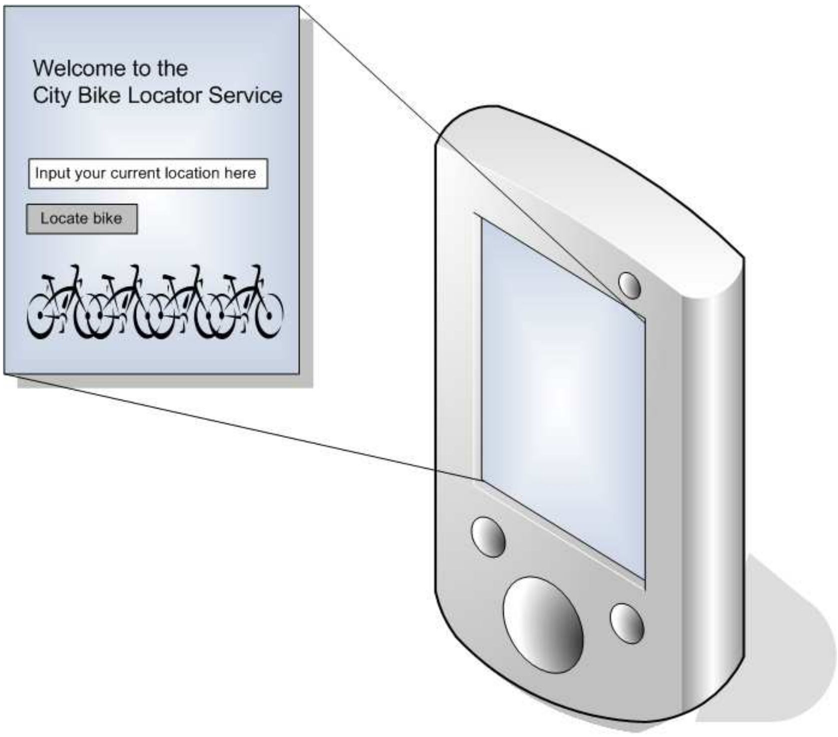


Figure 4.2: A possible user interface for the City Bike Locator service

Location information about the city bikes can also be useful when administrating the bike service. Popular routes can easily be identified, not limited to where the bike was rented and where it was returned. This can simplify the process of adapting the service to the actual utility patent of the bikes. Support for locating misplaced bikes or missed bikes that are not returned properly on time can also be supported.

4.2.2 Find Your Friends

Social networking services are currently popular within the Internet communities. In such services, the users send messages to each other, comment each others photos and discuss upcoming events. The users also have the opportunity of manually inputting their current location or status information. However, it is possible to expand this type of service to include automatic location information with the use of Wi-Fi RFID tags attached to the users.

The Find Your Friends service utilizes location information collected from users carrying Wi-Fi RFID tags. The users can use the service to be notified about the friends that currently are in the neighborhood. The location information can also be used to show status messages, telling whether the user is at home, at work or out in the city. The latter can be related to whether the user is available for a chat or up for a coffee. Figure 4.3 illustrates how this service can inform the users about friends that are within a given perimeter.

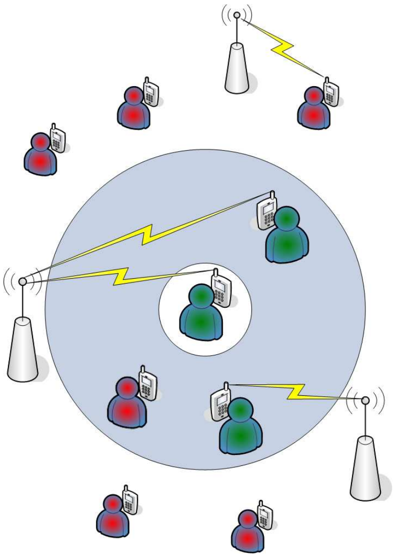


Figure 4.3: The Find Your Friends service. Green color indicates friends within the specified perimeter. Red color indicates users that are not located, because they are outside the perimeter or set to not available.

4.2.3 Emergency Alarm

The safety of people is a concern in many cities today. Attempted rapes and violence assaults are examples of problems causing such concerns. In many of the cases, there can be limited time for calling the emergency number on a cellular phone. An emergency alarm with a simpler way of alerting the police in emergency situations could be a solution to reduce this kind of problems. The majority of the Wi-Fi RFID tags available in the market are equipped with optional buttons. Hence, such tags can be used for emergency purposes in citywide wireless networks.

The Emergency Alarm service utilizes Wi-Fi RFID tags as alarm buttons. In case of emergency, a call button on the tag can be pressed to notify the police or other security personnel. The Wi-Fi infrastructure can then be used to pinpoint the location of the person in need for help. Figure 4.4 illustrates how the Wi-Fi RFID tag can be pressed in order to alert security personnel.

Figure 4.4: The use of a Wi-Fi RFID tag as an emergency alarm

Chapter 5

Test Planning

The main goal in this Master's thesis is to survey the performance of Wi-Fi RFID tags in a deployment like Wireless Trondheim. The requirements to the performance of such tags will vary among different LBSs. Hence, comprehensive testing is important to identify what kind of services that currently can be supported. This chapter presents five test scenarios that are being carried out in order to examine the performance of the tags. The testing equipment and how the five test scenarios are carried out is also described.

5.1 The Testing Equipment

5.1.1 Wi-Fi RFID Tags

A total of three Wi-Fi RFID tags are used in the test scenarios. All the three tags are AeroScout T2 Wi-Fi RFID tags with tag software version 4.1. The AeroScout T2 tag is depicted in Figure 5.1. The operation of this type of tag is described in greater detail in Chapter 2.

5.1.1.1 Tag Parameter Configuration

Unless stated otherwise, the tag beaconing interval is set to 10 seconds in all tests. The tags are configured to transmit on channels 1, 6 and 11, as all these channels are used within Wireless Trondheim. The transmission power is set to the default value of +18 dBm, which is approximately 63 mW. The message repetition rate is set to 1, causing only a single multicast frame to be sent with every transmission.

Figure 5.1: The AeroScout T2 Wi-Fi RFID tag

With these settings, the tag battery life time is stated to be 195 days [3]. The tags are also configured to use the WDS frame format, as this is required for the tags to be located by the Cisco LBS solution used in Wireless Trondheim [25]. The address configuration in the WDS frame format is described in more detail in Appendix E. The three tags, their corresponding MAC address and configuration are shown in Table 5.1.

Tag number	*MAC Address*	*Beaconing interval*	*Channels*	*Message repetition*
1	00:0c:cc:5d:49:d7	10 sec	1, 6, 11	1
2	00:0c:cc:5d:49:d8	10 sec	1, 6, 11	1
3	00:0c:cc:5d:49:d9	10 sec	1, 6, 11	1

Table 5.1: The three AeroScout T2 tags used in the test scenarios

5.1.2 AeroScout Tag Activator

Before use, the AeroScout T2 tags have to be activated and configured. The AeroScout Tag Activator is used for this purpose. The tag activator is a proprietary access point, which communicates with the tags' short-range 125kHz receiver. Up to 50 tags can be programmed simultaneously with the tag activator, and the tags must be placed within 1 meter from the access point [4]. The tag activator is connected to a computer using a crossed Ethernet cable, and the software

AeroScout Tag Manager is used in the configuration process. Further details about the tag configuration using the Tag Activator and the Tag Manager are described in Appendix B.

5.1.3 Wireless Infrastructure

The Wireless Trondheim infrastructure is based upon the Cisco Unified Wireless Network architecture presented in Chapter 2. Figure 5.2 shows the Wireless Trondheim architecture, which is utilized in the testing of the Wi-Fi RFID tags.

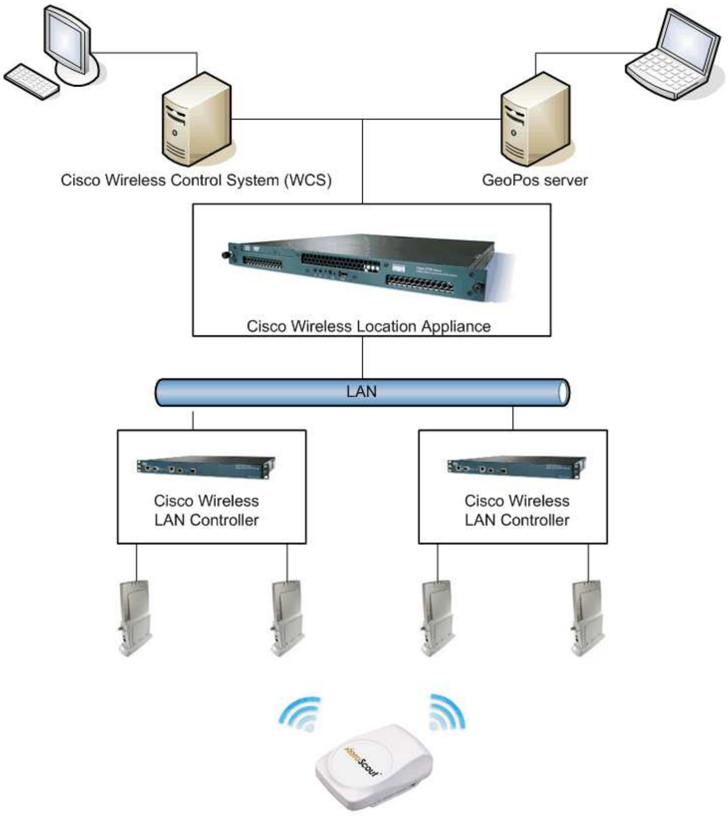


Figure 5.2: The WLAN infrastructure architecture used in the Wi-Fi RFID tag testing, based on sub pictures from [18] and [22]

All access points that receive the Wi-Fi RFID tag multicast frame collect RSSI information about the corresponding tag. The access points then aggregate this information to the access point controller, which is responsible for the specific access point. At a configured interval, the location server polls all the controllers for location information, and computes the tag location based on the collected RSSI values. In all the tests, the location server polling interval is set to 30 seconds for Wi-Fi RFID tags. The location server also utilize location smoothing algorithms to compensate for changes in the RSSI that are not caused by tag movements, but by factors such as obstacles and rotations of the tags. Five different smoothing factors can be configured through the WCS interface. The chosen configuration is then applied to all clients and Wi-Fi RFID tags that are located through the location-based network solution. The different options for the location smoothing are listed in Table 5.2

Location smoothing value	*Weight assigned to previous location*	*Weight assigned to new location*
Off (no smoothing)	0%	100%
Less smoothing	25%	75%
Average smoothing	50%	50%
More smoothing (default)	75%	25%
Maximum smoothing	90%	10%

Table 5.2: The location smoothing options and their weight assignments, from [25]

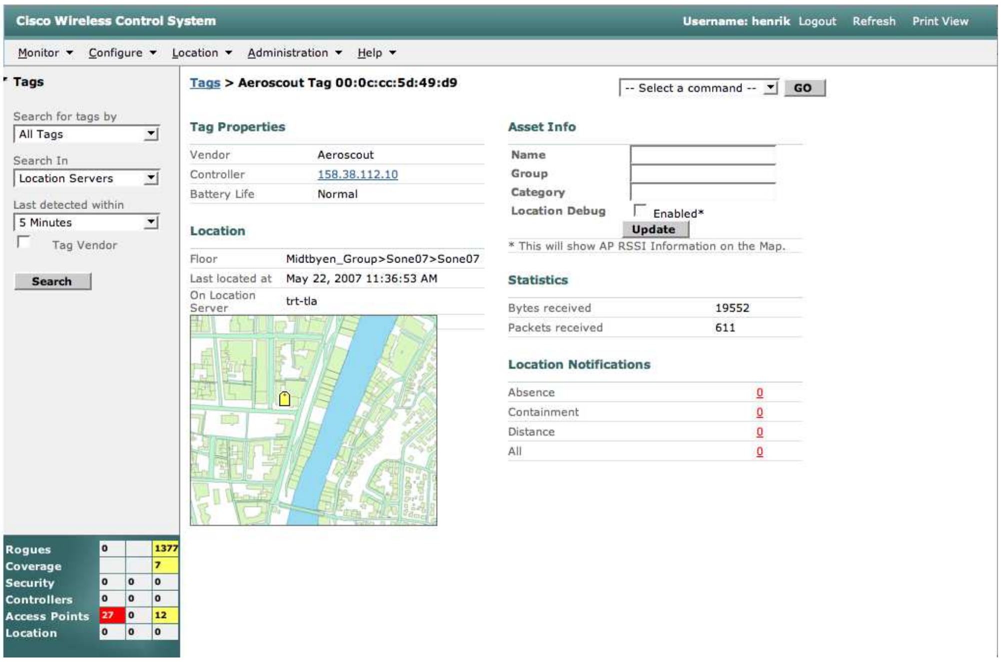
Low smoothing factors are recommended for tags that are in motion [25]. Hence, the less smoothing value is used in the test scenarios, unless stated otherwise.

5.1.4 WCS Web User Interface

The Cisco solution deployed in Wireless Trondheim includes a software tool for planning and monitoring the wireless network. This software, the WCS, runs on a separate server and communicates with the location server. The WCS Web User Interface is available through a regular web browser and is used to interface with the WCS server. This web interface is used in the test scenarios to monitor the tag location, as illustrated in Figure 5.3. RSSI information about the tag from the surrounding access points is also available from the WCS maps.

Tag location monitoring in WCS can be done through three different maps. In two of the maps, the tag location is generated based on location information from the location server. In the last map, tag location information is collected directly from the WLAN controllers. The different WCS maps are illustrated and explained in Appendix D.

The city center of Trondheim is divided into 16 coverage zones in the WCS. Each of these zones is graphically represented by a detailed map showing the access



Tags > Aeroscout Tag 00:0c:cc:5d:49:d9

Search for tags by: All Tags
Search In: Location Servers
Last detected within: 5 Minutes
☐ Tag Vendor

Tag Properties

Vendor	Aeroscout
Controller	158.38.112.10
Battery Life	Normal

Location

Floor	Midtbyen_Group>Sone07>Sone07
Last located at	May 22, 2007 11:36:53 AM
On Location Server	trt-tla

Asset Info

Name:
Group:
Category:
Location Debug: ☐ Enabled*

* This will show AP RSSI Information on the Map.

Statistics

Bytes received	19552
Packets received	611

Location Notifications

Absence	0
Containment	0
Distance	0
All	0

Rogues	0		1377
Coverage			7
Security	0	0	0
Controllers	0	0	0
Access Points	27	0	12
Location	0	0	0

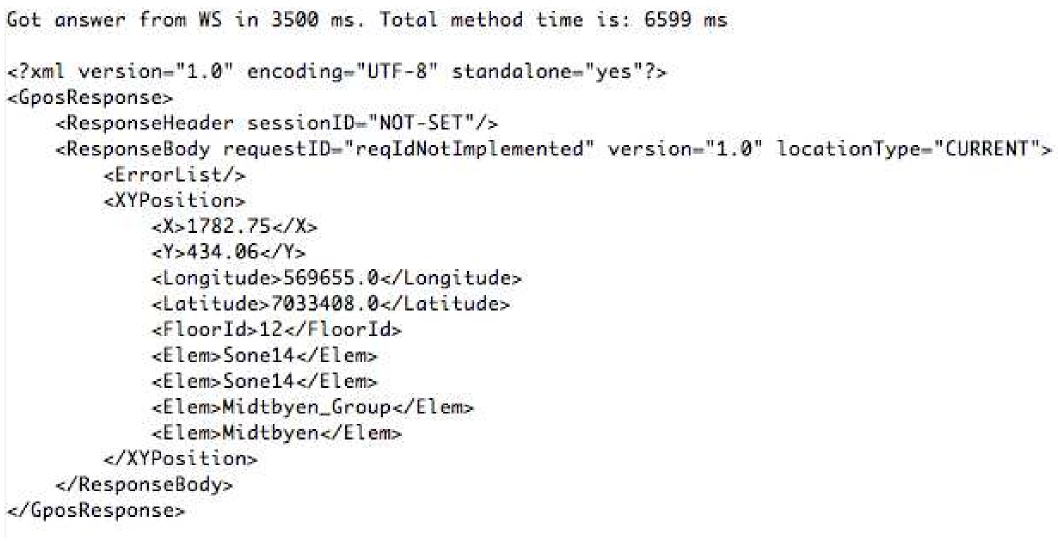
Figure 5.3: The web interface of the Cisco Wireless Control System showing detailed information about a located Wi-Fi RFID tag.

points, clients and Wi-Fi RFID tags within the zone. The zone maps that contain the test locations are included in Appendix A.

5.1.5 The GeoPos Web Service

The Cisco WCS interface is a powerful tool for monitoring and controlling the wireless network. However, this software is not suited for fetching location information in relation to LBS. Such services require handling of location information with respect to privacy and security. For this use, the Cisco Wireless Location Appliance offers a XML/SOAP API, which can be used by third party applications. The Geographical Positioning Service (GeoPos) is a location brokering service available at NTNU, which uses this API [5]. GeoPos can be used for LBS purposes in Wireless Trondheim to get location information securely from the location server.

In the tests, a Java-based client program is used to interface with the GeoPos Web Service. The client requests the location by sending the tag's MAC address, together with a username and password to the GeoPos server. The server responds with an XML string with the coordinates of the tag, if it is found in the network. GeoPos gives the coordinates in the European Reference Frame 1989 (EUREF89) reference system with Universal Transverse Mercator (UTM) datum. The GeoPos Web Service XML response is illustrated in Figure 5.4.



```
Got answer from WS in 3500 ms. Total method time is: 6599 ms

<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<GposResponse>
    <ResponseHeader sessionID="NOT-SET"/>
    <ResponseBody requestID="reqIdNotImplemented" version="1.0" locationType="CURRENT">
        <ErrorList/>
        <XYPosition>
            <X>1782.75</X>
            <Y>434.06</Y>
            <Longitude>569655.0</Longitude>
            <Latitude>7033408.0</Latitude>
            <FloorId>12</FloorId>
            <Elem>Sone14</Elem>
            <Elem>Sone14</Elem>
            <Elem>Midtbyen_Group</Elem>
            <Elem>Midtbyen</Elem>
        </XYPosition>
    </ResponseBody>
</GposResponse>
```

Figure 5.4: The XML response from the GeoPos Web Service

The GeoPos Java client is compiled and run in the open source development platform Eclipse SDK 3.2.1. The Java source code is available in the electronic attachment.

5.1.5.1 Additional Hardware

To monitor the tag location, additional hardware is used when performing the tests. An Apple PowerBook G4 is used as the monitoring client, interfacing with the Cisco WCS server and the GeoPos server. To be able to compare the computed locations with the real-time location, a Bluetooth-enabled TomTom Mk-II GPS receiver is used. Further details regarding the additional hardware are found in Appendix B.

5.1.5.2 Additional Software

The laptop is running Mac OS X version 10.4.9. Additional software is used together with the laptop when performing the tests. This software is described in brief below.

MacStumbler is a Mac OS X utility, which identifies the access points that currently cover the laptop. MacStumbler also shows the signal strength from each of the access points, as measured by the wireless interface card in the laptop. MacStumbler 0.75b is used when performing some of the test scenarios to identify the surrounding access points.

RouteBuddy is a GPS navigation software for Mac OS X. A demo version of RouteBuddy 1.2 is used to get the location coordinates from the GPS receiver. RouteBuddy gives positioning information in decimal degree format with the World Geodetic System (WGS84) datum.

ArcGIS/ArcMap is a map-authoring software from the Geographic Information System (GIS) company ESRI. ArcMap version 9.1 is used to plot the point coordinates of the real life location and the location given by GeoPos, and to compute the error distance between these points. The error distance computation is described more detail in Appendix B.5. Special map files covering the city of Trondheim are also used together with this software.

The GPS receiver and the GeoPos service use different geographic reference systems. Thus, conversion is needed in order to compare locations. The GPS coordinates are converted using the web based Geographic/UTM Coordinate Converter [45], before being plotted in ArcMap. Conversion is also done using a special Java class, called GeoTrans, in order to plot some of the locations using the GoogleMaps API [26]. The GeoTrans Java source code is attached electronically.

5.2 Performing the Test Scenarios

All the tests scenarios are carried out within the city center of Trondheim and in dry spell weather conditions. As described in Chapter 3, the entire city center is currently not covered by the Wireless Trondheim deployment. Hence, specific test locations within known coverage areas are chosen before performing the scenarios. Maps showing these locations and the access points that cover the areas are available in Appendix A. Some of the scenarios are also performed during movement between areas with and without coverage. These test scenarios are carried out in order to identify whether a tag can be used in real-time applications, such as tracking the location of highly mobile items.

5.2.1 Monitoring the Tag Location

The computed tag location is recorded from the graphical WCS interface or the GeoPos Web Service. When searching for tags in WCS, the search criteria is set to tags that are detected by the location server within the last 5 minutes. The tag details are then displayed by following the hyperlink on the tag's MAC address in the search results. The larger map available from the tag details is used record RSSI information about the tag from the surrounding access points. This map is illustrated in Figure 5.5.

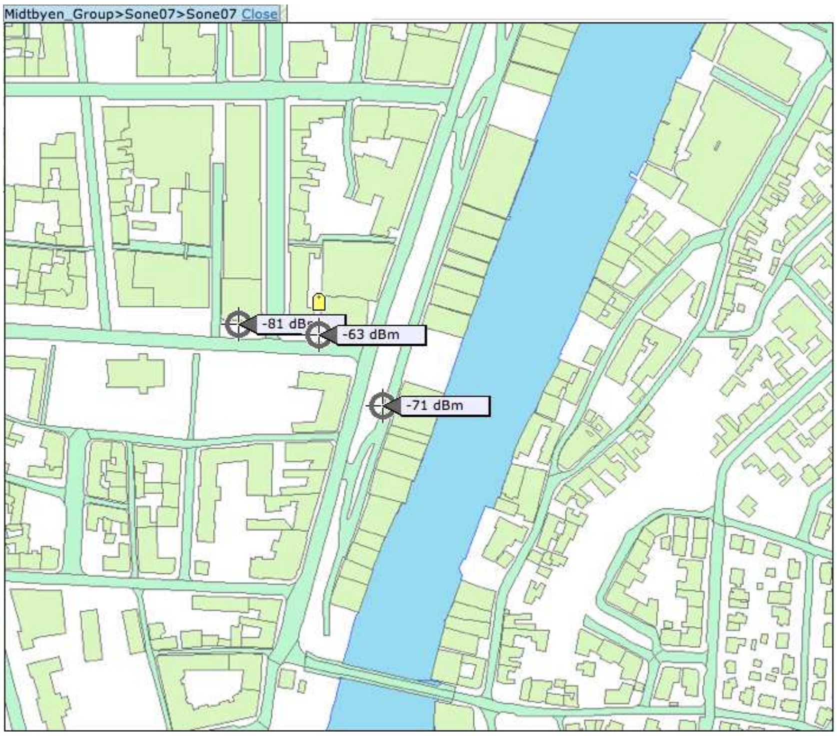


Figure 5.5: Tag monitoring in WCS. Detailed map with yellow marker indicating the tag location. The three surrounding access points that receive the tag messages, and the RSSI values they measure from the tag are also shown in this map.

The WCS is a cumbersome interface for testing, as its purpose is maintenance and control of the network. Hence, the GeoPos service is used additionally to get the computed location coordinates. As described above, GeoPos can offer a secure interface to the location server for LBSs in Wireless Trondheim. In addition, GPS coordinates are recorded in some of the tests, to identify the real-life location more accurately than through the WCS maps.

5.3 The Five Test Scenarios

A total of five test scenarios are performed in order to survey the performance of the Wi-Fi RFID tags in Wireless Trondheim. These scenarios are listed below.

5.3.1 Scenario 1: Indoor Versus Outdoor Location

The purpose of this test scenario is to compare the Wi-Fi RFID tag location accuracy in indoor and outdoor environments. The indoor test is performed inside the shopping center at Solsiden, one of the few indoor areas explicitly covered by Wireless Trondheim. In the indoor test, the tag is placed at a static location for 10 minutes. Each minute during this time period, the computed location is recorded from GeoPos. The locations are then plotted in ArcMap together with the real-life location, and the error distances are computed as described in Appendix B.5. The values are then compared with the results from the tests performed in Scenario 3, static outdoor location. The indoor test is run only once, resulting in 10 computed location values.

5.3.2 Scenario 2: Maximum Distance From Access Point

The purpose of the second test scenario is to find the maximum distance between the Wi-Fi RFID tag and an access point, where the tag can be identified and located. The maximum distance test is performed at Marinen, one of the few areas within Wireless Trondheim that currently is covered by a single access point only. In this test, the tag is moved slowly from outside the coverage area, towards the access point. The laptop and the software MacStumbler are used to monitor the signal strength from the access point, in order to identify the coverage area. When the tag appears on the WCS map, the location coordinates are recorded from the GPS receiver and the location is plotted in ArcMap. The distance between this location and the access point is then computed as in the previous scenario. The error distance between the real-life location and the computed location is also found in ArcMap in the same way as in the first test scenario.

5.3.3 Scenario 3: Static Location

The purpose of this test scenario is to examine the location accuracy when the tag stays at a static location for a small time period. The scenario is divided into two sub tests, to see if there are any differences in the location accuracy with the number of access points that cover the area.

In both sub tests, the tag is placed at a specific location for 10 minutes and the according GPS coordinates are recorded. Every minute during the time period, the computed location coordinates are recorded from the GeoPos response. In addition, a screen shot is taken from WCS, in order to observe the RSSI values measured by the surrounding access points. When both sub tests are finished, all the coordinates given by GeoPos are plotted in ArcMap, together with the converted GPS coordinates. Finally, the distances between the real-life location and the computed locations are computed in the same way as in the two previous test scenarios.

5.3.3.1 Sub Test 1: Single Access Point

This sub test is carried out at Marinen, where only a single access point covers the area. The access point is operating in mesh mode, wirelessly interconnected to another access point. Two distinct locations are chosen, and the tag is placed static at each location for 10 minutes. The test is run three times consecutively, by alternating between each of the two locations. This results in a total of 30 location measurements.

5.3.3.2 Sub Test 2: Multiple Access Points

This sub test is carried out at Torget. This area is covered by several access points, all with wired connection to the distribution system. This enables location determination using triangulation based on RSSI values from several access points when computing the location. The tag is placed at two distinct locations, and the test is run three times at each of the locations. As in the previous sub test, this results in 30 location measurements.

5.3.4 Scenario 4: Dynamic Location

The purpose of the fourth test scenario is to see whether movements within a coverage area are detected by the location-based network solution. To what degree such movements affect the location accuracy is also observed. This test is carried out in two different coverage areas; at Solsiden and at Torget. Multiple access points cover both these areas. At Solsiden, the tag is moved to 10 arbitrary locations. Each of these locations are identified approximately by the surrounding objects and plotted in ArcMap. At Torget, the tag is moved to 5 arbitrary locations, where the locations coordinates are identified using the GPS receiver. In both coverage areas and at each of the arbitrary locations, a screen shot from WCS is taken to record RSSI values. The location coordinates are recorded by performing a GeoPos request at each location. The distances between the computed locations and the real-life locations are finally computed in ArcMap.

5.3.5 Scenario 5: Real-time Location Tracking

The goal with this test scenario is to identify whether the Wireless Trondheim deployment can support real-time services for tracking highly mobile items. In this test, a bike is used when traveling throughout the city center. The tag is mounted to the bike's steering bar. The test route is depicted in Figure 5.6.

Figure 5.6: The route used in the real-time test. A one minute stop is performed at each of the 12 locations marked with numbers on the map, and the current time and location is recorded. The figure is based on screen shot from GoogleMaps [26]

At 12 different locations, a one minute stop is performed and the current time is written down. The laptop is used to monitor the tag location by configuring the

GeoPos client automatically to request the tag location coordinates every second minute. These coordinates are consecutively written to a file. A digital watch is synchronized to the laptop's clock, to be able to compare the results. After finishing the test route, the recorded locations are compared with the locations given by the GeoPos responses. The GeoPos coordinates are converted from UTM to latitude and longitude using the GeoTrans Java class and plotted using the Google Maps API.

This test scenario is divided into three sub tests to see whether the location smoothing algorithm used by the location server and the tag transmission power affect the location accuracy.

5.3.5.1 Sub Test 1: With Location Smoothing

In the first sub test, the location smoothing algorithm is set to the less smoothing value, which is used in the rest of the test scenarios. The new location is then given a three times higher weight than the previous location in the computation of the current tag location.

5.3.5.2 Sub Test 2: Without Location Smoothing

In the second sub test, the location smoothing algorithm is turned off. The previous location and the current location are then given equal weight in the location computation. This is done in order to identify whether the location smoothing degrade the location results.

5.3.5.3 Sub Test 3: Lower Tag Transmission Power

In the third sub test, the tag transmission power is reduced to +15 dBm. This is done in order to identify whether the relatively high default transmission power value degrade the location accuracy. The location smoothing is still turned off.

Chapter 6

Test Evaluation and Results

The five test scenarios described in Chapter 5 are performed within Wireless Trondheim. The main test results are presented in this chapter. All the computed location coordinates and other detailed results are found in Appendix G.

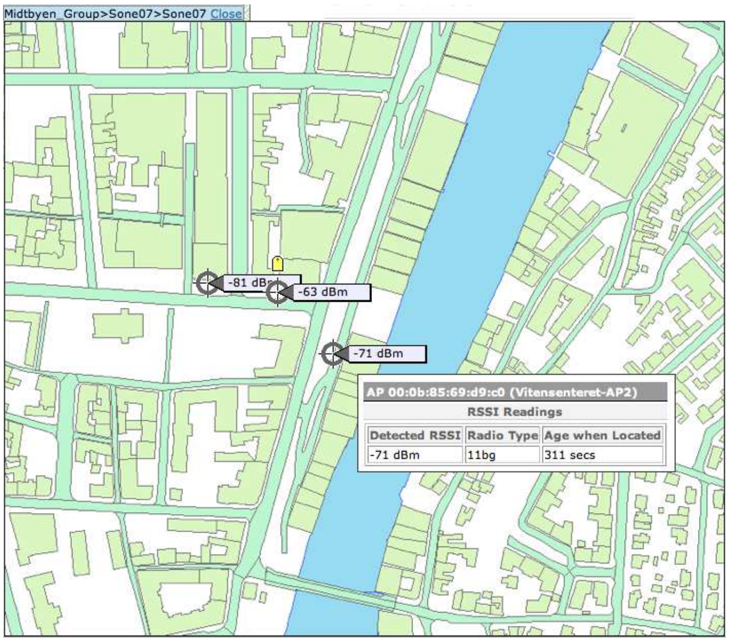
6.1 General Observations

In all the five test scenarios there is a problem with delays in the computed locations. This problem occurs when moving the Wi-Fi RFID tag between adjacent coverage zones. Figures 6.1 and 6.2 on the next page illustrate how this problem becomes present when a tag is moved from Zone 7 to Zone 6 in Wireless Trondheim.

At the time of arrival in Zone 6, the computed tag location is still in Zone 7. Figure 6.1 shows how the time since the tag was located increases to beyond 5 minutes. Consecutive messages sent by the tag every 10 seconds during the next minutes do not affect the computed location in WCS, even though Zone 6 have several access points, which should have received these messages.

The computed tag location appears in the correct zone 15 minutes after arrival in Zone 6, as depicted in Figure 6.2. Another step-by-step example of the delayed location problem is available in the electronic attachments. More information on how to access these attachments is available in Appendix F.

When this delayed location problem occurs in the tests, the location values collected during this time period are excluded. The data from the succeeding minutes after the tag appears in the correct zone are used instead. This solution is chosen in order to prevent the problem to cause biased results.

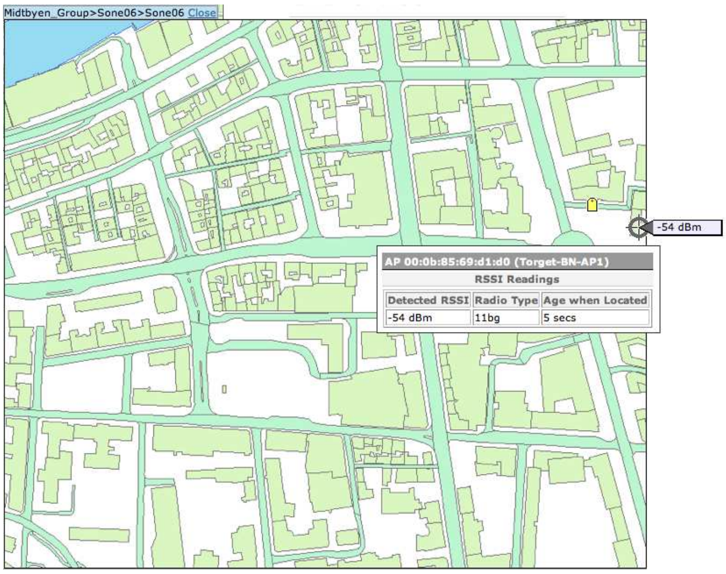


AP 00:0b:85:69:d9:c0 (Vitensenteret-AP2)

RSSI Readings

Detected RSSI	Radio Type	Age when Located
-71 dBm	11bg	311 secs

Figure 6.1: At 10:32, the tag arrives in Zone 6, but is shown to be in the Zone 7. The age-when-located parameter shows that the tag has not been located for 311 seconds.



AP 00:0b:85:69:d1:d0 (Torget-BN-AP1)

RSSI Readings

Detected RSSI	Radio Type	Age when Located
-54 dBm	11bg	5 secs

Figure 6.2: At 10:47, the tag appears in the correct coverage zone, 15 minutes after arrival in zone 6. The age when located parameter is now down to 5 seconds.

Another observation made during the testing, is that the computed locations tend to be close to an access point. Thus, the location accuracy seems to increase the closer the tag is located an access point. This observation turns out to be valid both in areas with single and multiple access point coverage.

6.2 Indoor Versus Outdoor Location Accuracy

The results from the indoor test in Scenario 1 show that a tag can be located with an accuracy of less than or equal to 10 meters with a 60% precision. These results are not in accordance with the location accuracy specifications stated by Cisco in [25], where an accuracy of less than or equal to 10 meters with a 90% precision is given. However, this precision is stated to be applicable for best practice indoor deployments, which utilize the RF fingerprinting technique described in Chapter 2. This location determination technique is not applicable in Wireless Trondheim, as no RF calibration is performed within the coverage areas. In addition, the indoor test is only performed once, with the use of only ten values in the computation of average error distance. Thus, the achieved results are not statistically significant. The results still give a indication of the accuracy and precision that are achievable in the indoor coverage areas of Wireless Trondheim. The ten computed indoor location results are shown in Table 6.1.

Longitude	*Latitude*	*AP RSSI values*	*Error distance*
570443	7034826	-61/-74/-72	19 m
570437	7034834	-61	18 m
570423	7034848	-60/-86	2 m
570421	7034850	-60/-90	4 m
570442	7034827	-60/-90	27 m
570427	7034844	-59/-90	5 m
570425	7034847	-58/-89	2 m
570422	7034849	-61/-89	2 m
570421	7034850	-62/-89	4 m
570442	7034821	-60/-72/-72	32 m

Table 6.1: The results of the indoor location test. Multiple RSSI values indicates that several access points are used in the location computation.

The results from the outdoor location test in Scenario 3, static location, which are presented in a separate subsection below, show that none of the computed tag locations are within 10 meters from the actual outdoor location. The results demonstrate that a tag can be located with an accuracy of less than or equal to 50 meters with 93% precision at the first location and with a precision of 60% in the second location. The results are only achieved in an area with multiple access point coverage. It is important to point out that these results also are based on a small number of measurements. Thus, the results are giving indications on the performance rather than having statistically significance. By comparing the results from the indoor test and the results from the third test scenario, it is possible to conclude that the location accuracy is degraded outdoors.

6.3 Maximum Distance

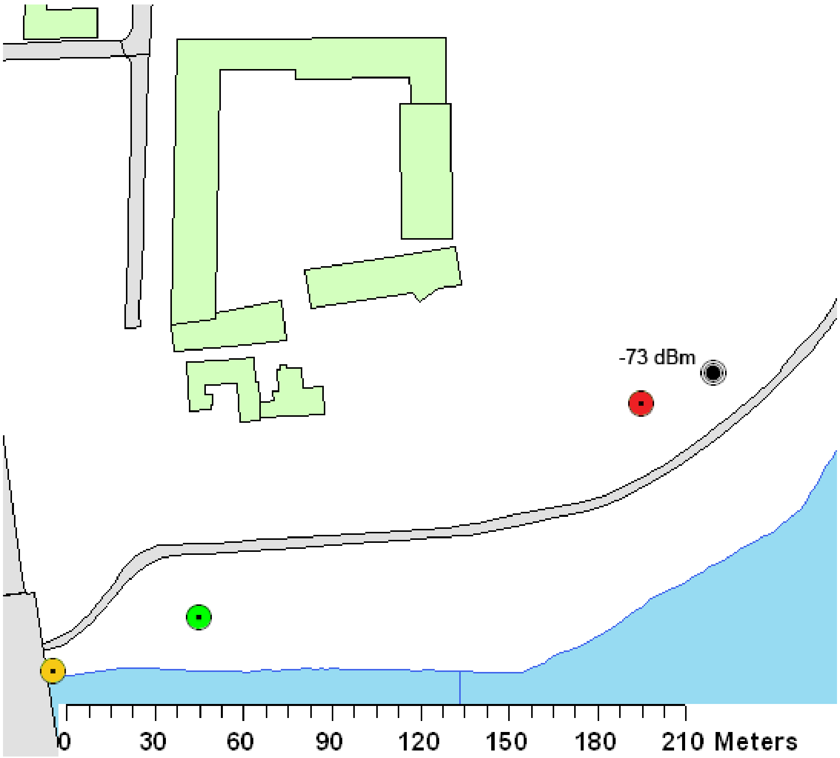


Figure 6.3: The maximum distance where the tag can be located. Green color illustrates the real-life location. Red color illustrates the computed location. The yellow circle denotes the location where the tag messages are received by an access point in the adjacent coverage zone. The distance between the green circle and the access point is the maximum distance.

The problem with delays in the computed location is present in the maximum distance test scenario. It is difficult to determine the specific location where the tag can be identified even if the tag is moved slowly towards the access point coverage area. Thus, the embedded motion sensor in the AeroScout tag is utilized when performing the test. The tag is configured to transmit only every 3 hours when at rest, and to transmit every 10 seconds during movements. The tag is then left at rest before the test and moved slowly towards the coverage area until it appears within the actual coverage zone.

The results from the maximum distance test scenario show that a tag can be identified and located at distances approximately 200 meters away from the access point. However, the location accuracy is poor at these distances, with errors of approximately 175 meters, as depicted in Figure 6.3. The computed location is also very close to the access point. Thus, the error distance is almost the same as the distance between the tag and the access point. The tag's RSSI is measured to -73 dBm by the access point at the maximum distance.

When the tag is moved further away from the access point, the tag signals are received by an access point in the adjacent coverage zone. The computed location is reflected by this and the tag is shown to be close to the other access point. This access point is located approximately 200 meters in another direction.

The maximum distance test is only performed in an area covered by a single access point. The degree of location accuracy is therefore limited by no triangulation possibilities. However, the results obtained in this test agree with the tag outdoor range of a approximately 200 meters stated by AeroScout in [3].

6.4 Static Outdoor Location

6.4.1 Single Access Point

The results from the first part of Scenario 3, single access point, show that the majority of the computed locations coincide with the location of the access point. These locations are approximately 94 meters away from the real-life location of the tag. The access point is located 116 and 108 meters respectively from the two test locations. Thus, the distances from the tag to the access point are approximately equal to the computed error distances.

In the first test run at the first test location, there are some variations in the computed location. Three of the computed locations are not inside the coverage area of the actual access point, but close to an access point covering the adjacent zone. These three values are from three consecutive minutes, where the tag is located by one of the access points in the adjacent zones. Figure 6.4 illustrates both how the computed locations are close to the first access point and the three values that are in the wrong coverage zone. The three different test runs, are marked with different colors in the figure. Each of the test runs have 10 location measurements. However, many of the computed locations are equal and are therefore not visible in the figure.

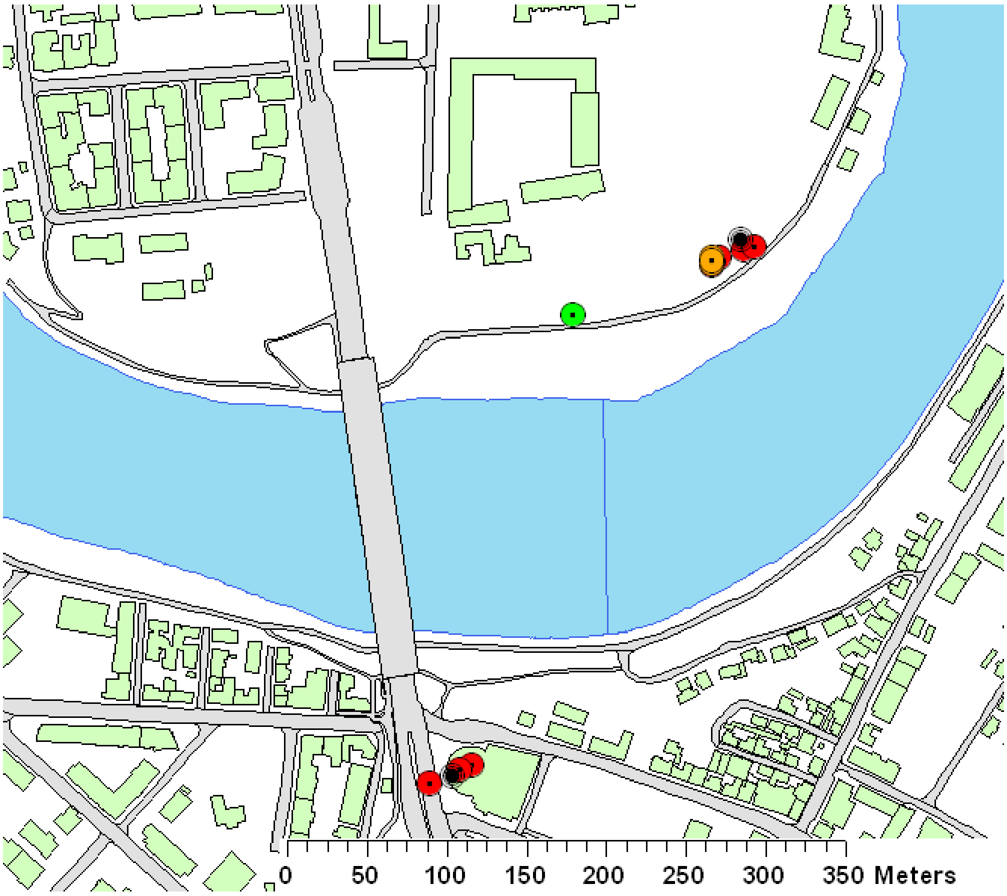


Figure 6.4: The first static location at Marinen. All computed locations, except three, are close to the access point. The computed locations are depicted with red, blue and orange circles. Some locations are equal to each other and are therefore not visible in the figure. The real-life location of the tag is indicated with the green circle. Black circles indicate access points

At the second test location, all the computed locations coincide at around 20 meters from the access point. The error distance is approximately 90 meters in all three test runs, as shown in table 6.2.

Test run	*Average error distance*
1	91,2 meters
2	91 meters
3	90,7 meters

Table 6.2: Average error distances at the second static location at Marinen.

6.4.2 Multiple Access Points

In the second part of Scenario 3, up to four different access points report RSSI information about the Wi-Fi RFID tag. The results show that the location accuracy varies greatly within each test run. There are also differences between the average error distances among the three test runs. Figure 6.5 shows the results from the first location. The three different test runs are plotted with different colors, and some of the distances from the real-life location are also shown in the figure.

Figure 6.5: The first static location at Torget. There are considerable variations in the computed location. The real-life location of the tag is indicated with the green circle.

The total average error distance in the results from the first location is approximately 30 meters. Table 6.3 shows the average error distances in each of the test runs, together with the percentage of values that are within 30 meters from the real-life location. In each of the three test runs, 10 location measurements are taken.

Test run	*Average error distance*	*Less or equal to 30m*
1	33,3 meters	50%
2	35,9 meters	70%
3	17,1 meters	90%

Table 6.3: The average error distances in the static location test, multiple access points

As with the first static location, the results from the second location show variations in the computed locations. These locations are also close to the nearest access points, in the same way as in the first part of Scenario 3. Figure 6.6 show the results from the second location.

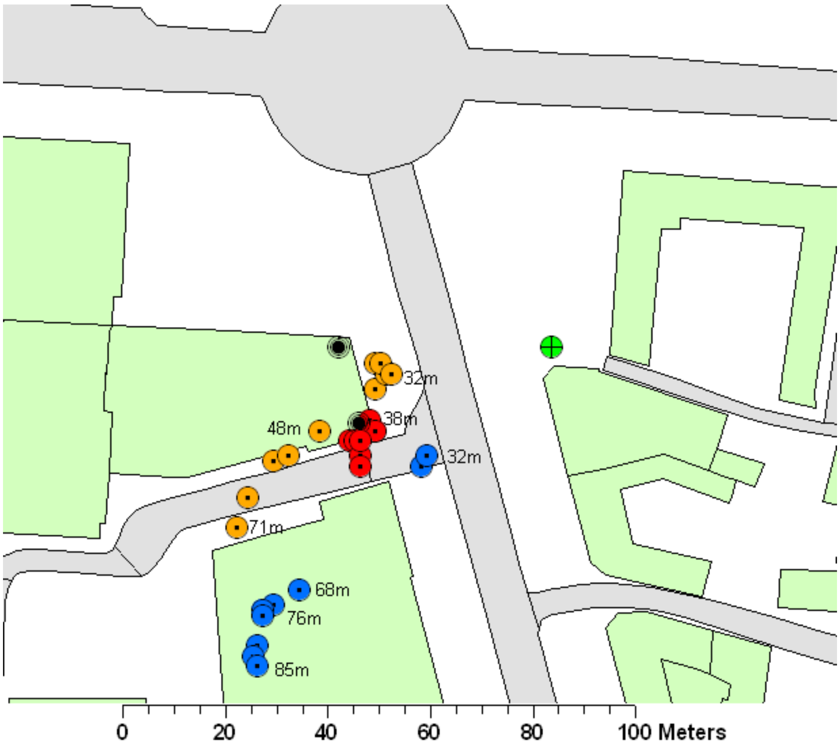


Figure 6.6: Test results, static location, multiple access points, location 2.

The average error distance among the three test runs at the second location is approximately 50 meters. Table 6.4 lists the average error distances in each of the test runs. The percentage of values that are within 50 meters from the real-life location is also shown in the table. Each of the test runs have 10 location measurements.

Test run	*Average error distance*	*Less or equal to 50m*
1	40,7 meters	100%
2	69,7 meters	20%
3	46,6 meters	60%

Table 6.4: The average error distances in the static location test, multiple access points

The above results show that a tag can be located within approximately 50 meters if several access points cover the area. Comparing the results from the first and second parts of Scenario 3, it is possible to conclude that the location accuracy is better when multiple access points cover the area. Thus, triangulation based on RSSI values from multiple access points increases the location accuracy. This is in accordance with the location basics described in Chapter 2.

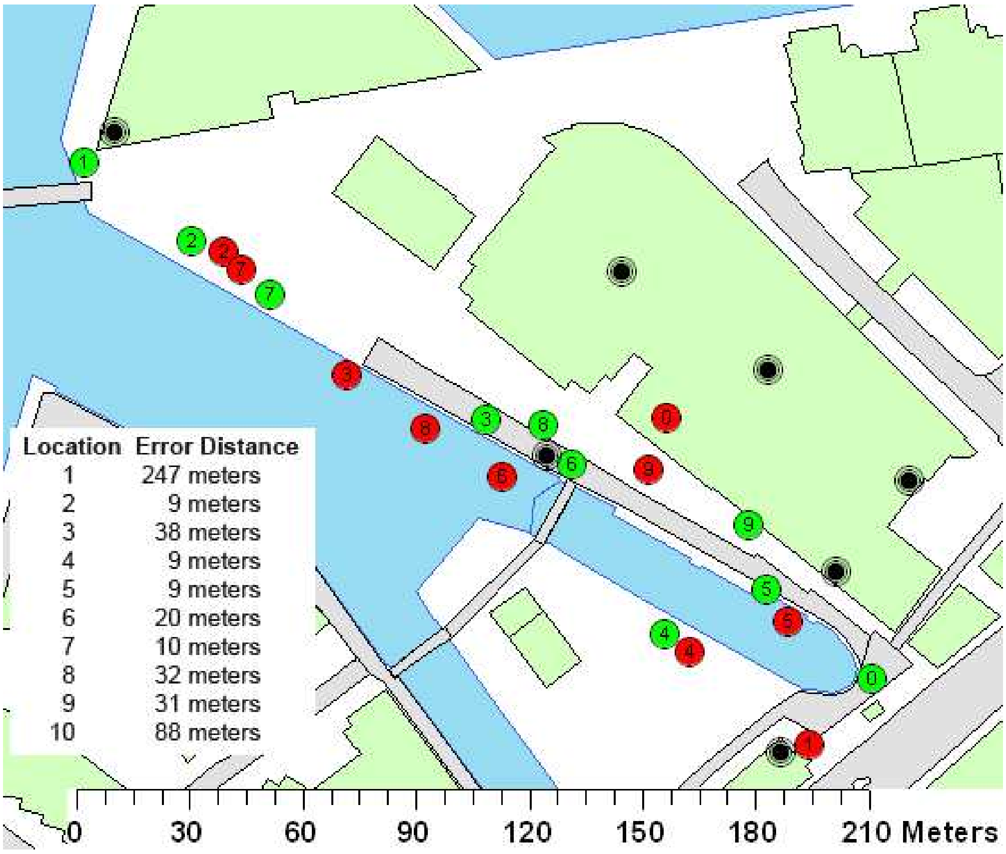
The two test locations are surrounded by tall buildings and several people and buses travel frequently across the area. This traffic is believed to affect the signals and cause multi-path effects that result in the observed variations in the computed location.

6.5 Dynamic Outdoor Location

The results from Scenario 4, dynamic outdoor location, indicate that movements over large distances in the coverage area are slowly reflected in the computed locations. In the first dynamic location test, the tag enters the coverage area from south and is moved by walking to the northern end of the area, where the first location is recorded. As depicted in Figure 6.7, the first computed location is at the southern end, over 200 meters away from the real-life location.

However, the computed location becomes more accurate after the next movement, where the accuracy is improved to 9 meters. The error distances vary during the next movements, and the total average error distance is computed to approximately 49 meters. The results also demonstrate that movements over shorter distances are more rapidly reflected in the computed location.

The results from the second dynamic location test are similar to the results from the first test. However, in this test, the computed locations are again close to



Location	Error Distance
1	247 meters
2	9 meters
3	38 meters
4	9 meters
5	9 meters
6	20 meters
7	10 meters
8	32 meters
9	31 meters
10	88 meters

Figure 6.7: The results of the dynamic location test at Solsiden. Green circles indicate real-life locations and red circles indicate computed locations. Equal numbers denote each of the five locations. Black circles represents access points. The error distances are also shown in the figure.

the access points in the coverage area. The average error distance is computed to approximately 44 meters. The results are found in Appendix G.

6.6 Real-time Location Tracking

In Scenario 5, all the location coordinates are recorded automatically every second minute from GeoPos. The results from the three bike tests illustrate how the problem with delays in the computed location occurs during movements between adjacent coverage areas, and how this problem affects the real-time performance of the LBS solution used in Wireless Trondheim. The test results from the real-time test scenario is also available in the electronic attachments.

6.6.1 With Location Smoothing

In the first bike test, the tag transmission power is the default value of +18dBm. The location server smoothing algorithm is set to less smoothing. The computed locations recorded from GeoPos at the time the tag passed each of the 12 test locations are depicted in Figure 6.8. Some of the computed locations are equal and are therefore not visible in the figure. The results show that the tag is mainly located at only five distinct areas during the test. It is possible to identify where the tag was moved from and some of the areas the tag passed by. However, the movements across several Wireless Trondheim coverage areas, such as Torget, are not reflected by the GeoPos responses.

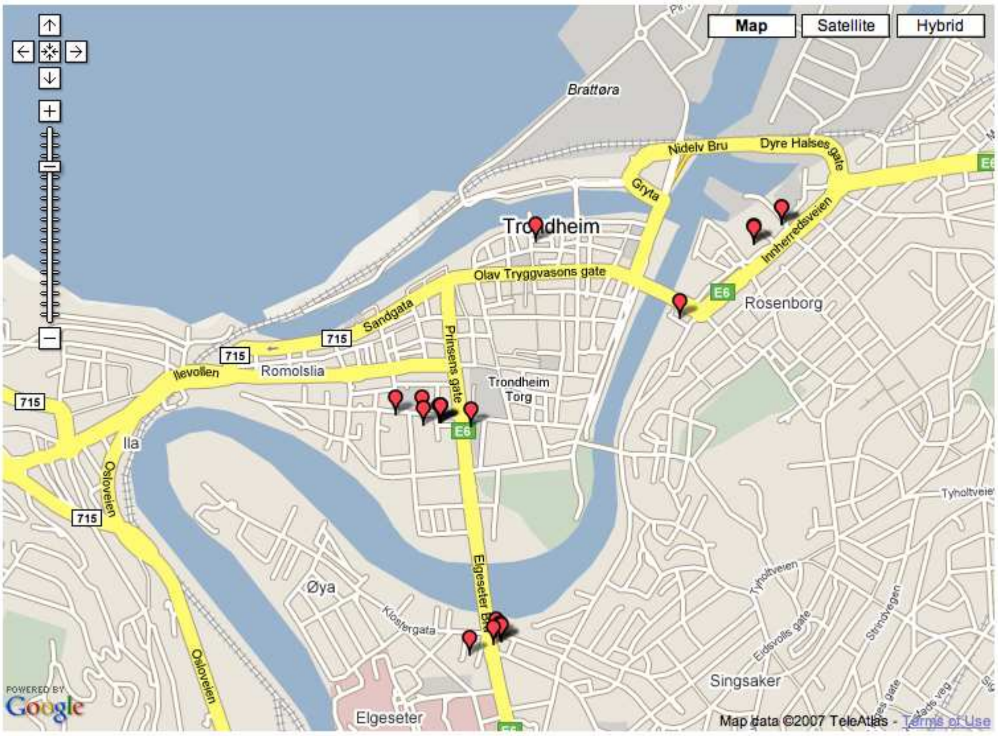


Figure 6.8: The results from the real-time test with location smoothing plotted in GoogleMaps [26]

6.6.2 Without Location Smoothing

In the second bike test, the transmission power is also set to the default value of +18 dBm, but the smoothing algorithm in the location server is turned off. Figure 6.9 illustrates the results of this test. Again, the computed locations are delayed when moving between coverage areas. The results now show that several computed locations have equal coordinate sets. Hence fewer markers are visible in the figure.

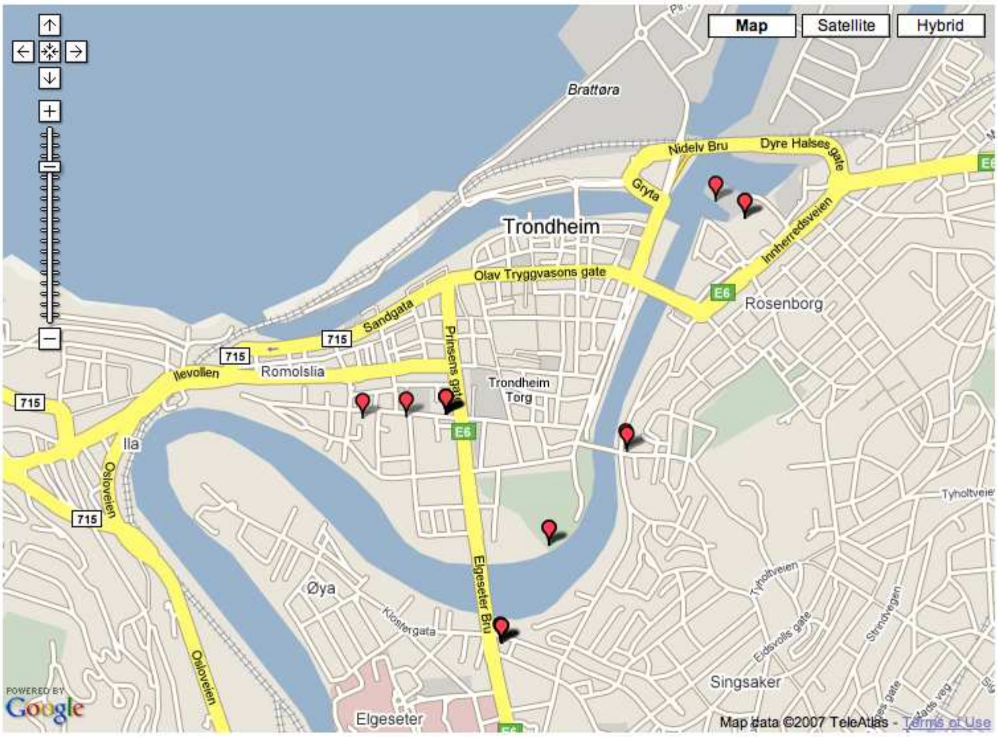


Figure 6.9: The results from the real-time test without location smoothing plotted in GoogleMaps [26]

6.6.3 Lower Tag Transmission Power

In the third bike test, the tag transmission power is turned down to +15 dBm. The smoothing algorithm in the location server is still turned off. Figure 6.10 illustrates the results of this test.

As these results show, the tag is now located in six main areas. However, the locations are pretty much equal to the results in the two other sub tests. Still, these results are better than in the previous two sub tests. Thus, the tag transmission power seems to affect the location accuracy to some lesser degree.

From the real-time test scenario results it is possible to conclude that there are currently limited possibilities for tracking a highly mobile Wi-Fi RFID tag throughout the Wireless Trondheim network.

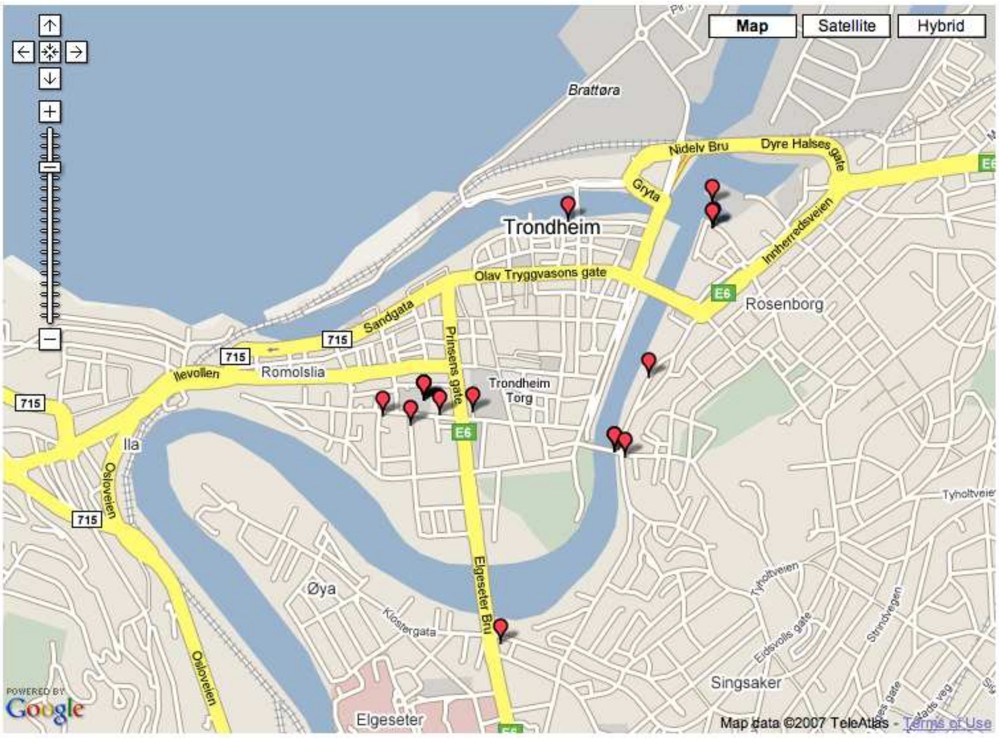


Figure 6.10: The results from the real-time with lower tag transmission power plotted in GoogleMaps [26]

6.7 Possible Error Sources

There are several error sources that can degrade the performance of Wi-Fi RFID tags outdoors. The most important error sources that are believed to affect the above test results are listed below.

6.7.1 External Antennas

The access points in Wireless Trondheim use external antennas. However, the Cisco location-based solution used in the deployment does explicitly not support location determination with the use of such antennas [30]. The computed locations are based on RSSI values measured at the access points, and an approximation of the distance based on such measurements. There are variations in the distance between an access point and the external antenna connected to it. Hence, the external antennas are believed to be a major error source to the accuracy of the computed tag locations.

6.7.2 Mesh Mode and Triangulation

In the WCS software version currently used in Wireless Trondheim, there is a limited support for location determination using triangulation. The location based solution is only able to perform triangulation based on RSSI values from access points with wired connection to the backbone network [30]. However, several of the access points in Wireless Trondheim are wirelessly interconnected with other access points. Hence, not all access points support triangulation. The limited support for triangulation is believed to be a major error source to the location accuracy.

6.7.3 Interference

The unlicensed 2.4 GHz frequency band is heavily utilized both by 802.11 stations and other wireless equipment. Thus, interference is a known problem in this frequency band [14]. The interference can cause problems for the access points in the reception of 802.11 frames. The Wi-Fi RFID tags used in the tests are configured to send only one frame with every transmission. If there is interference on the channel during a transmission, the access point may not receive this frame. In such cases, the tag location will not be reported. Interference is believed to be a considerable error source in some of the test results.

6.7.4 Access Point Placement in WCS

The location of the access points in Wireless Trondheim are input by the network manager in the Cisco WCS. However, there are inconsistencies in the placement of the access points among the different WCS maps. On the maps used to monitor the tag location within this work, there are visible errors in the access point location. These errors are believed to have substantial effect on the locations monitored through the WCS interface.

6.7.5 Number of Measurements

Due to the cumbersome monitoring of tag locations through the WCS interface, there is a very limited number of measurements in each of the performed test. Hence, the test results are not statistically significant. Variations in the measurements also affect the average values, which are based on only five to ten measurements. The limited number of measurements is believed to considerably affect the significance of the results.

6.7.6 Tag Transmission Power

The default Wi-Fi RFID tag transmission power of +18 dBm transmission is used in most of the tests. This transmission power is equal to 63 mW. In comparison, the 802.11 wireless card in the monitoring laptop has a radio output power of 15 dBm or about 35mW [21]. The relatively high transmission power used by the tags is believed to affect the location accuracy to some lesser degree.

6.7.7 Other Error Sources

6.7.7.1 Location smoothing algorithms

The location server utilize algorithms to compensate for variations in the computed location that are not caused by tag movements. These location smoothing algorithms affect the computed location. However, the bike tests show minimal differences in the computed locations when the location smoothing is turned off. Hence, the algorithms are believed to be a minor error source compared to the sources listed above.

6.7.7.2 Height of Access Points

Cisco state that all access points should be placed at equal heights throughout the wireless network [25]. In the Wireless Trondheim deployment, the external antennas are placed 3-5 meters above ground. Thus, the height is believed to have minimal impact on the location accuracy.

6.7.7.3 Location Coordinates

The location coordinates are recorded from a GPS receiver and the responses from the GeoPos service. Both coordinate sets can have errors. However, these errors are believed to be minimal compared to the impact from the other error sources listed above.

6.7.7.4 Coordinate Conversion

The testing equipment uses two different coordinate formats. The GPS receiver gives location coordinates in decimal degree format with the WGS84 datum, while GeoPos and ArcMap use the EUREF89 reference system with the UTM datum. Conversion is therefore performed when comparing the real-life location with the location given by GeoPos. Additional conversion is needed to plot the locations in Google Maps. GoogleMaps uses decimal degree format and the WGS84 datum [26]. However, the coordinate conversions are believed to have little influence on the accuracy compared to the other error sources described above.

Chapter 7

Discussion

In Chapter 4, three services that can utilize Wi-Fi RFID tags in a citywide wireless network are proposed. In this chapter, the reality in a possible implementation of these services is verified. A discussion is given in the light of the results from the tests performed within Wireless Trondheim, which are described in Chapter 6.

7.1 Location Requirements

The requirements to the performance of Wi-Fi RFID tags differ among LBSs. Particularly, the location accuracy and precision requirements of a service determine whether an implementation is possible with this type of tags.

The results from the five test scenarios carried out in this work point out considerable variations in the accuracy and the precision of the computed tag location. Hence, a potential LBS in Wireless Trondheim must tolerate such variations in order to currently utilize the Wi-Fi RFID technology. There are a very limited number of measurements in the performed tests. Hence, the obtained results are not statistically significant. However, the results give an indication of the performance of the Wi-Fi RFID tags and the location-based solution deployed in Wireless Trondheim.

The real-time requirements to the Wi-Fi RFID tag location are also important when considering the reality in the potential LBSs. Services such as RTLSs require that a tag can be located constantly during movements, in order to track highly mobile items. Real-time services demand on frequent transmission of tag messages. These transmissions must also be rapidly reflected in the computed location, to preserve the location accuracy during movements. The test results show problems with delayed location updates when a tag is moved between adjacent coverage areas in Wireless Trondheim. Such delays will have a large impact on the performance of RTLSs.

7.2 Battery Lifetime

Another important aspect when considering Wi-Fi RFID tag performance is the lifetime of the internal battery. There is a trade off between the tag transmission interval and the battery lifetime. As described above, different services require different degrees of real-time location reporting. An RTLS requires frequent transmission of tag messages, which will result in numerous battery replacements. Such replacements should also be taken into account when considering the potential of a particular LBS.

With the configuration used in the test scenarios, the battery will have to be changed every sixth month approximately. However, it is possible to extend this lifetime by utilizing the motion sensor if it is appropriate for the particular service.

7.3 Performance of Other Positioning Systems

The performance of other positioning systems will also affect the potential for LBSs based on Wi-Fi RFID tags. GPS is for instance commonly known to give a location accuracy of less than 10 meters in outdoor environments, as long as the receiver has line of sight to the GPS satellites [33]. Users familiar with the GPS technology will have similar expectations to the performance of LBSs based on Wi-Fi RFID tags, if the service is offered as an alternative to GPS.

7.4 The City Bike Locator Service

Finding the location of the nearest city bike rack corresponds to locating a tag, which is placed at a static location. As the test results from Wireless Trondheim show, a tag can be located with an accuracy of 30-50 meters at a static location if the area is covered by multiple access points. In areas with only one access point, a location accuracy of approximately 100 meters can be achieved. Currently, not all of the city bike racks in Trondheim are covered by multiple access points. However, in these areas the location accuracy can be improved by deploying more access points or by placing the access point and the bike rack close to each other. The latter will decrease the error distance, as the computed tag location to a considerable extent coincide with the access point location. Taking in to consideration that none of the bike racks are placed within 100 meters of each other, it should be possible to identify which of the bike racks the tag belong to by identifying which access points that report the tag location. Moreover, all the bike racks are located in different coverage zones of Wireless Trondheim. Hence, the zone that the tag is located in will also give an indication on which rack the tag is located in. The zone the tag is located in can currently be recorded from the GeoPos response.

In the City Bike Locator service, it is important to be able to differentiate between bikes that are available and bikes that are in use. This can be made possible by using a Wi-Fi RFID tag with an embedded motion sensor. The tag can then be configured to transmit at a relatively long interval in the rack and more frequently during movements. Thus, it can be possible to identify available bikes by how often the tag transmits. Transmission intervals based on the motion sensor will also extend the battery lifetime of the tags.

A problem that might affect the City Bike Locator service is the delay in location updates between coverage areas. The results show that a tag may not appear in the right area for a time period of up to 15 minutes after arrival. For this particular service, this means that a bike may not appear available in the right area until 15 minutes after the bike is delivered in a rack. The real-time test results also show that there currently are very limited support for tracking bikes during movements. Even though it is possible to identify some of the locations the bike pass by, the accuracy is less than satisfactory during movements throughout the Wireless Trondheim coverage areas. Thus, the tag performance constrain the possibilities for using the service for the administrative purposes described in Chapter 4. For these purposes, where real-time location tracking is essential, the GPS technology is currently more appropriate for location determination, as it gives better accuracy during movements in outdoor environments.

7.5 The Find Your Friends Service

The Find Your Friends Service locate users based on the Wi-Fi RFID tag they carry. In its basic implementation, the service is a on-demand service, where the users request the location of their friends. The level of location accuracy determine whether the location is given as a set of location coordinates plotted on a map or simply in which part of the city center they are. The latter corresponds with locating the coverage zone, in which a tag currently is located. As the results of the testing show, it is currently possible to determine the zone by performing a GeoPos request. A person can then be identified to be for instance at Torget or at Solsiden. However, the problem with delayed location updates when traveling between coverage zones constrains the reliability of getting the correct location in this service. Movements from one area to another are currently very slowly reflected in the computed location. An acceptable degree of location accuracy can therefore be difficult to obtain until the person has been in the certain area for a time period.

As with other LBSs that track user locations, there are privacy concerns with respect to the location information. In Norway, the Norwegian Data Inspectorate restrict such services for privacy protection purposes [27]. However, the Wi-Fi RFID tags do not carry information about the user, as it only transmit a identification number. As long as the binding between this number and the user is protected in a database somewhere, a malicious access point will not be able to gather information about the users.

7.6 The Emergency Alarm Service

Emergency services have strict requirements to the performance of the tags. In emergency situations it is important that the location can be identified with high accuracy and precision. The test results show that several improvements must be done in order to achieve such a performance with the Wi-Fi RFID tags. Additionally, a service that is to be used for emergency purposes requires a high level of reliability. The service must be fault tolerant and available for the users at all times.

In Wireless Trondheim, there are several factors that affect the reliability of a potential LBS. The wireless infrastructure has no dedicated power supply, as the access points are placed at different premises throughout the city center. Some of these premises are private, where the owner is responsible for the power supply available for the access point. Due to the lack of central power control, the wireless infrastructure is therefore vulnerable for local power outages.

There are also a potential problem for sabotage on the wireless equipment, especially the antennas that are placed visible on buildings and lamp posts 3-5 meters above ground. Both a reliable power supply and properly secured infrastructure elements should be accomplished before an emergency service can be implemented.

7.7 Considerations on Business Potentials

LBS are believed to have substantial business potentials in Wireless Trondheim. The Wi-Fi RFID technology can enable such services and contribute to new sources of revenue for the network and content providers. However, the results presented in Chapter 6 point out several limitations with the Wi-Fi RFID tags and the location-based network solution currently used in Wireless Trondheim. These limitations put constraints on the possibilities of supporting LBS in the citywide wireless network today. Consequently, it is difficult to determine the current business potential for LBS in Wireless Trondheim. Prior to launching commercial LBS for the purpose of making revenues, the location accuracy and real-time support should be improved within the wireless network. Evidently, Wi-Fi RFID tags will then have a wider range of applications than today and constitute a larger potential for the support of LBS in Wireless Trondheim.

The business potential of Wi-Fi RFID can also be further extended with the use of 802.11 compliant chips that are embedded on regular SIM cards. This solution, known as WLANSIM was patented by Telenor and Radionor Communications in cooperation in 2003/2004 [44]. The WLANSIM function in the similar way as an active Wi-Fi RFID tag, but have the advantage of enabling LBS, regardless of the type of mobile terminal. Hence, the user does not need to carry an additional RFID tag in order to use the offered LBS.

Chapter 8

Conclusion and future work

The main goal with this Master's thesis is to survey the performance of the Wi-Fi RFID technology in citywide wireless networks. The performance determine the potential commercial services that can utilize Wi-Fi RFID tags in a deployment like Wireless Trondheim. In this chapter, a conclusion is given on the current performance, based on the discussion in Chapter 7. Additional guidelines for the future work are also presented.

8.1 Conclusion

Five test scenarios are carried out in this Master's thesis, in order to examine how Wi-Fi RFID tags perform in Wireless Trondheim. The results from these scenarios show that the accuracy of the computed tag locations varies throughout the Wireless Trondheim coverage areas. The accuracy is also influenced by the number of access points, which cover the particular area. In areas covered by multiple access points, an accuracy less or equal to 50 meters can be achieved with a reasonable level of precision. In areas with only one access point, the corresponding accuracy is degraded to approximately 100 meters. The results also indicate that a higher degree of accuracy is achieved when the Wi-Fi RFID tag is situated at a static location, than during movements. The above results are based on too few measurements to be statistically significant. Nevertheless, the results give an important indication on the tag performance in an outdoor environment.

Several limitations with the Wi-Fi RFID technology are revealed in the test results. The variations in the computed location are considerable both among the different test scenarios and within each part of tests. There is also a major problem with delayed location updates when traveling between different coverage areas.

The discovered limitations put constraints on the currently possible applications of Wi-Fi RFID tags in Wireless Trondheim. Real-time services and other LBSs with strict requirements to the location accuracy are currently not supported by the Wi-Fi RFID technology in this outdoor environment. However, on-demand services that only require that a tag can be located within a certain area or coverage zone can be implemented to some extent. Still, more comprehensive testing is needed in order to verify that a particular service currently can work well with the Wi-Fi RFID tags.

The technological limitations make it difficult to determine the current business potential of services utilizing Wi-Fi RFID tags. Currently, the support for LBS is limited. Several improvements should be done in order to achieve an acceptable performance of Wi-Fi RFID tags with the location-based network solution in Wireless Trondheim.

8.2 Future work

The results presented in this report give indications on the performance of the Wi-Fi RFID technology in a citywide network. This performance determine the current applications of Wi-Fi RFID tags in such an environment. However, more thorough testing is necessary before commercial services can be launched using this kind of tags. Several more performance measurements should be carried out in order to achieve statistically significant results. Experimenting with different Wi-Fi RFID tag configurations should also be performed in order to provide a better basis for the performance of the tags. Different tag transmission power, beaconing intervals and message repetitions should be tested, as well as tuning of the location based network solution.

The next Cisco WCS software version is stated to support outdoor location tracking [30]. Some of the limitations revealed in this Master's thesis will possibly be improved in this release. Hence, more thorough testing of the Wi-Fi RFID tag performance should be carried out to verify this outdoor support.

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Appendix A

Coverage Zones

The city center of Trondheim is divided into 16 zones in the Cisco WCS, as depicted in Figure A.1. Yellow color indicates zones experiencing interference and red color indicates zones with access points that are not working. Green color indicates that all the access points in the zone are functioning properly.

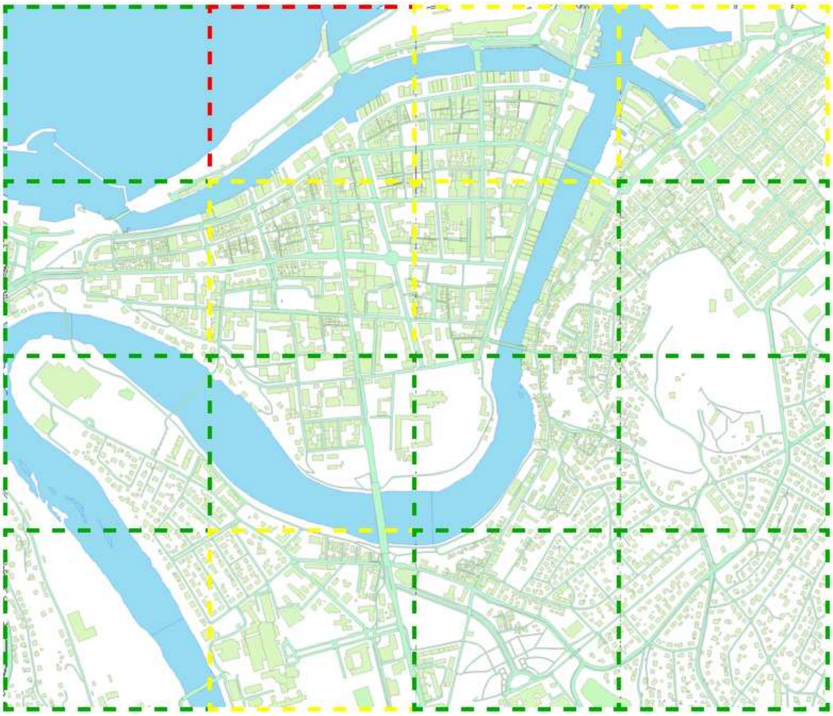


Figure A.1: The city center of Trondheim divided into 16 coverage zones, derived from Cisco WCS.

The zones are numbered from 1 to 16, starting from the upper left corner. However, not all of the zones are currently covered by the Wireless Trondheim deployment.

In the WCS user interface, each of the 16 zones can be viewed in greater detail. The test scenarios in Chapter 5 have been carried out in zone 4 (Solsiden), zone 6 (Torget) and zone 11 (Marinen). Detailed maps showing each of these three zones and where the access points are located within the zone are found below.

A.1 Zone 4: Solsiden

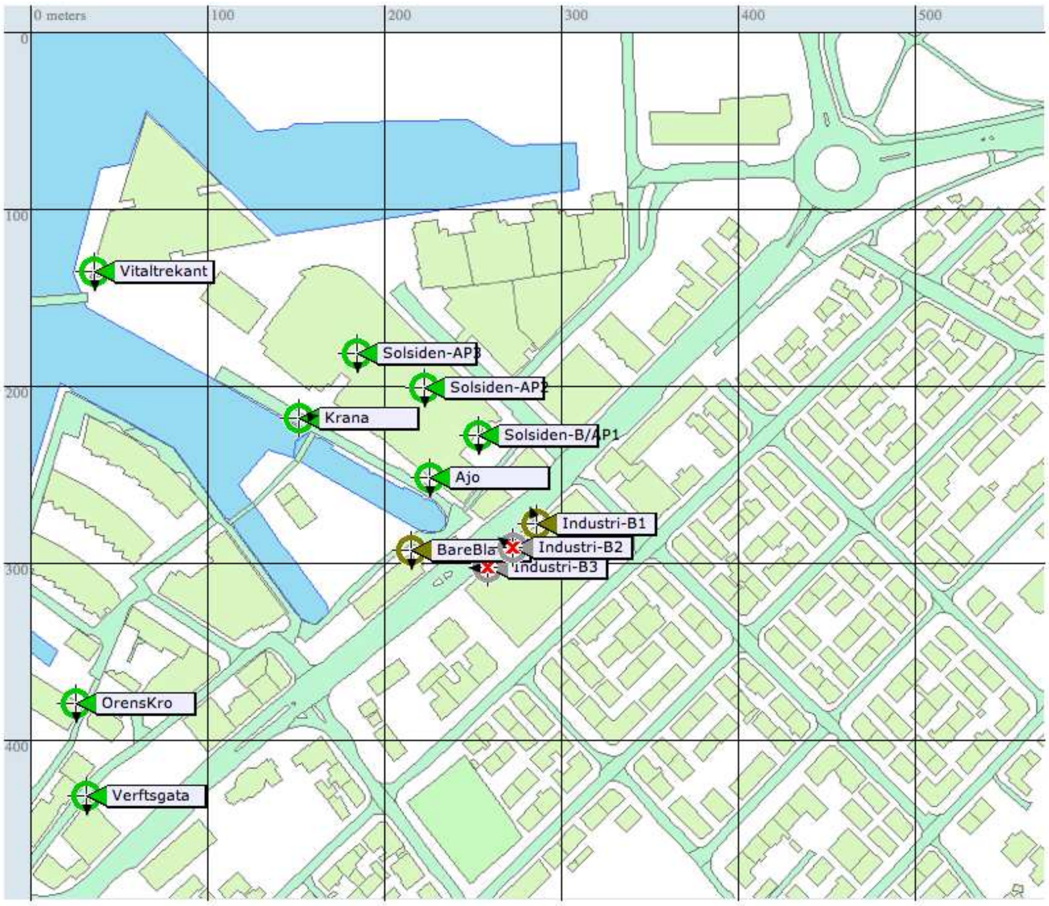


Figure A.2: The Solsiden coverage zone, derived from Cisco WCS

Yellow color indicates access points that experience interference to a certain extent. The red crosses indicate bridges. Green color indicates that the access point is working properly without any significant interference.

A.2 Zone 6: Torget

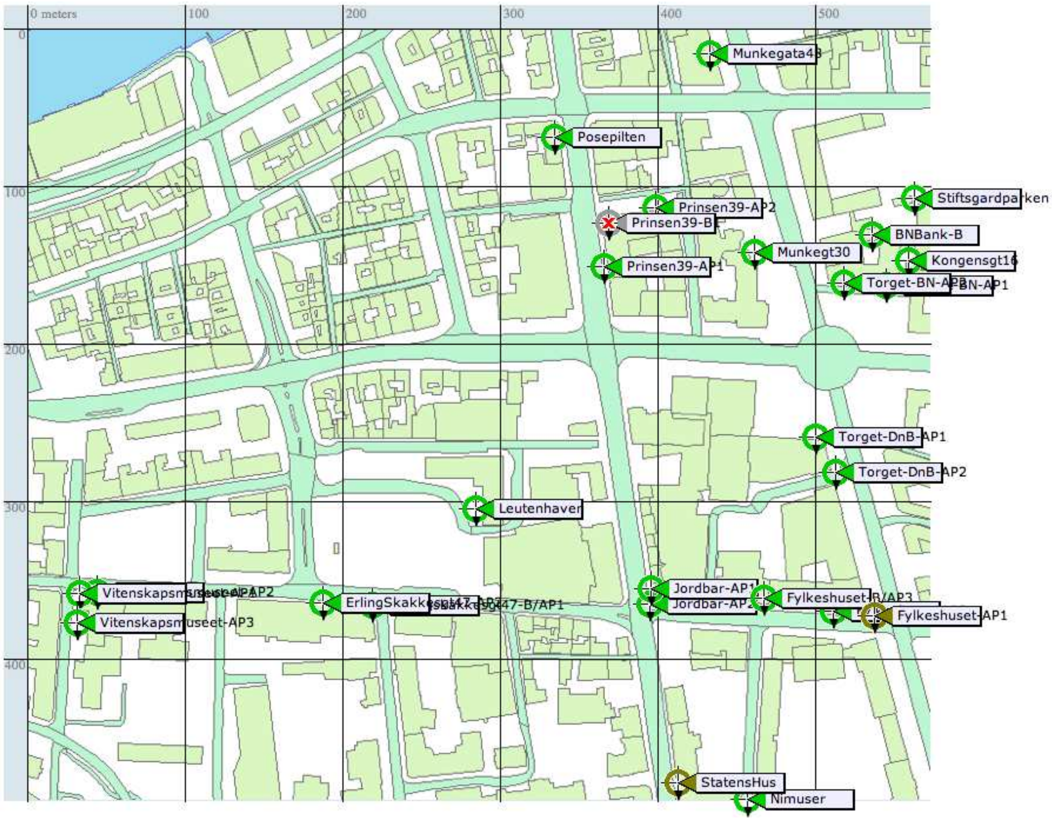


Figure A.3: The Torget coverage zone, derived from Cisco WCS

The area surrounding the roundabout at Torget, where some of the static outdoor location tests are carried out, is covered mainly by four different access points. All these access points have wired connection do the distribution system. This enables triangulation possibilities based on several RSSI values when the location is determined by the location server.

A.3 Zone 11: Marinen

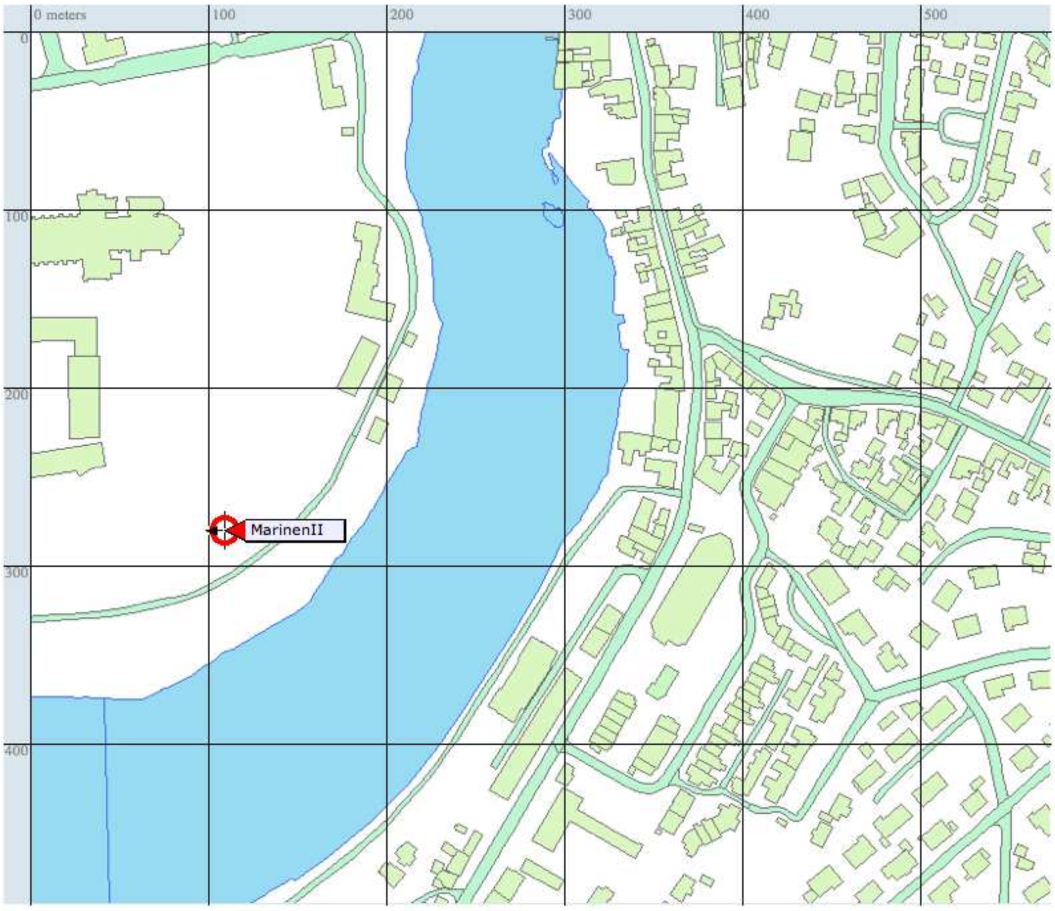


Figure A.4: The Marinen coverage zone, derived from Cisco WCS

Marinen is covered by a single access point. In the figure above, the access point is marked with red color, which indicates that the access point was out of function at the time the screen shot was taken.

Appendix B

Testing equipment

B.1 AeroScout T2 Wi-Fi RFID Tag

Radio	IEEE 802.11b compliant (2.4GHz)
Transmission power	Up to +19dBm (81mW)
Range	Up to 200m outdoor. Up to 60m indoor
Power	3.6V Lithium
Dimensions	62mm x 40mm x 17mm

Figure B.1: The AeroScout T2 tag. Figure and specifications are from [1]

Transmission interval	*1 channel, 1 transmission repetition*	*1 channel, 2 transmission repetitions*	*3 channels, 1 transmission repetition*	*3 channels, 2 transmission repetitions*
1 second	64 days	33 days	22 days	11 days
5 seconds	275 days	151 days	104 days	54 days
10 seconds	1.27 years	275 years	195 years	104 years
30 seconds	2.33 years	1.64 years	1.27 years	275 days
1 minute	2.95 years	2.33 years	1.92 years	1.27 years
3 minutes	3.59 years	3.24 eyars	2.95 years	2.33 years
5 minutes	3.75 years	3.51 years	3.3 years	2.8 years
30 minutes	3.97 years	3.93 years	3.88 years	3.75 years
1 hour	4 years	3.75 years	3.95 years	3.88 years

Table B.1: Estimated battery life times for the AeroScout T2 tag, from [3]

B.2 Apple PowerBook G4

Model	Apple PowerBook G4 12-inch SuperDrive
Processor	1.5GHz PowerPC G4
Memory	1.25GB PC2700 (333MHz) DDR SDRAM
Hard disk drive	80GB Ultra ATA /100, 5400 rpm
Wireless	Built-in IEEE 802.11g 54-Mbps AirPort Extreme Built-in Bluetooth 2.0+EDR
System software	Mac OS X 10.4.9 (8P135)

Figure B.2: Apple PowerBook G4 12-inch. Figure and specifications are from [20]

B.3 TomTom Wireless Mk-II GPS receiver

MAC Address	00-0d-b5-66-41-45
Protocol	NMEA 0183 Version 2.2
Datum	WGS-84
Update rate	1Hz
Bluetooth	Class II Version 1.2

Figure B.3: TomTom Mk-II GPS receiver. Figure and specifications are from [9]

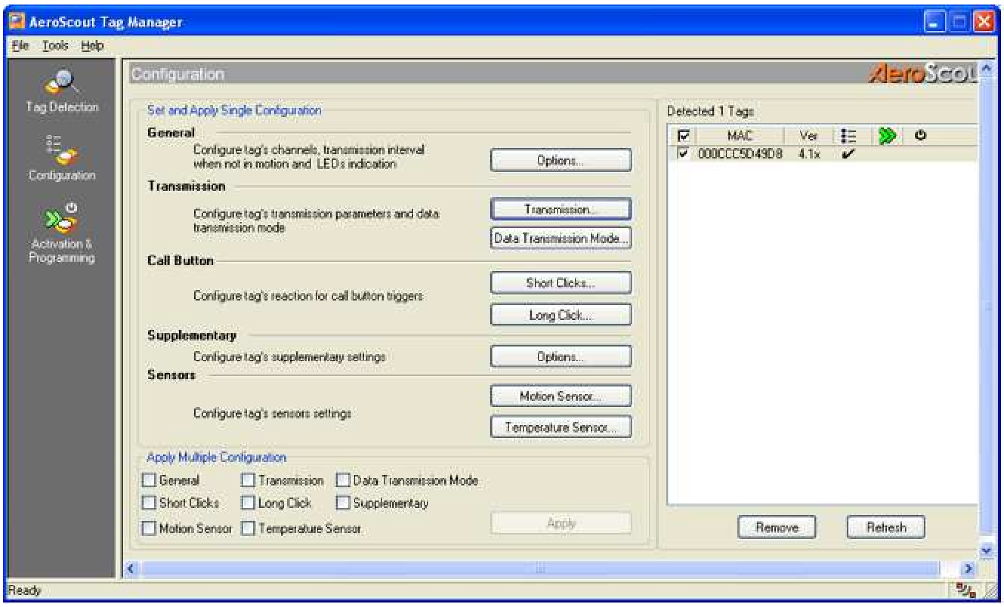
B.4 AeroScout Tag Activator and Tag Manager

To enable and configure the AeroScout T2 tags, the AeroScout Tag Activator and a stationary computer running Microsoft Windows XP Professional are utilized. The tag activator is illustrated in Figure B.4

Figure B.4: Programming tags with the AeroScout Tag Activator

The tag activator is connected to the computer using a crossed Ethernet cable. The default IP address of the Tag Activator is 192.168.1.235 and its subnet mask is 255.255.255.0. The computer is set to use the IP address 192.168.1.200, as it has to be on the same subnet as the Tag Activator. The tags are to be programmed, must be placed within one meter from the tag activator.

The AeroScout Tag Manager software is used to interface with the tag activator. All tag configuration is done through the tag manager user interface shown in Figure B.5.



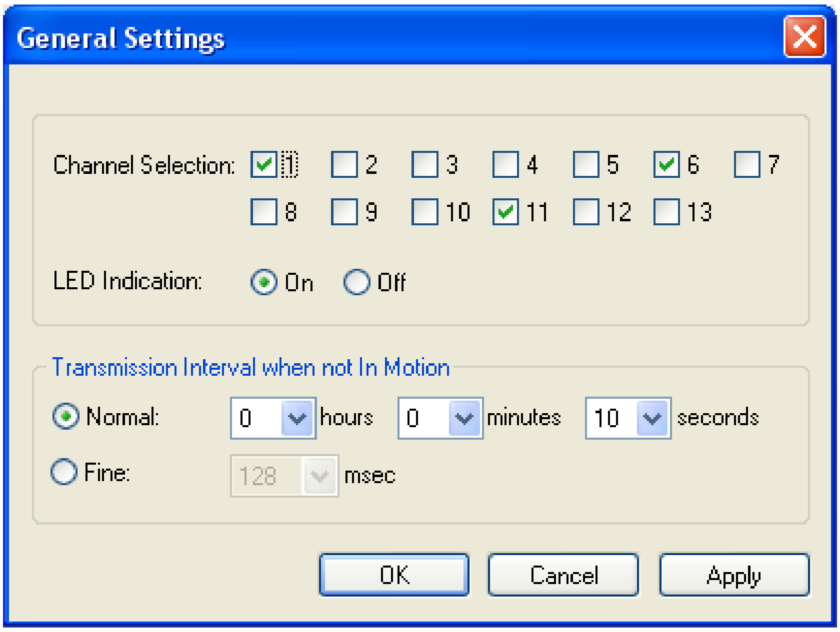
☑	MAC	Ver
☑	000CCC5D49D8	4.1x

Figure B.5: Configuring a tag with the AeroScout Tag Manager

The AeroScout T2 tag can be configured to transmit on up to three channels. Figure B.6 illustrates the use of channels 1, 6 and 11 and how the tag beaconing interval is set to 10 seconds.

The transmission power can be set to up to +19 dBm. A message can be repeated up to 10 times with each transmission. The data frame format can be either WDS or IBSS. These configurations are illustrated in Figure B.7.

The embedded motion sensor in the AeroScout T2 tag can be utilized for more frequent transmissions when the tag is being moved. Figure B.8 illustrates how the transmission interval is set to 10 seconds when a motion of the tag is sensed.



Channel Selection: ☑ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☑ 6 ☐ 7
☐ 8 ☐ 9 ☐ 10 ☑ 11 ☐ 12 ☐ 13

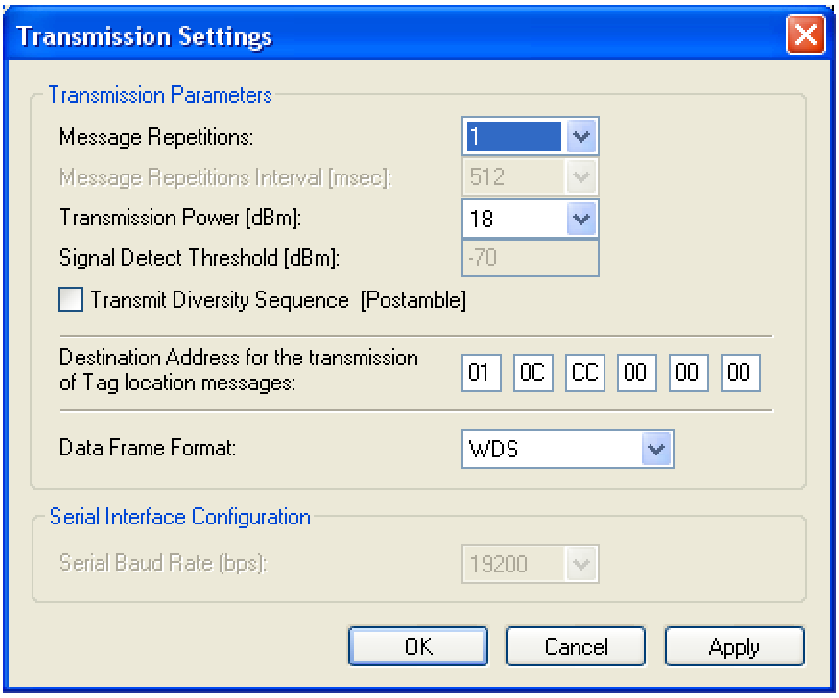
LED Indication: ● On ○ Off

Transmission Interval when not In Motion

● Normal: 0 hours 0 minutes 10 seconds

○ Fine: 128 msec

Figure B.6: Configuring the tag transmission channels



Transmission Parameters

Message Repetitions: 1

Message Repetitions Interval [msec]: 512

Transmission Power [dBm]: 18

Signal Detect Threshold [dBm]: -70

☐ Transmit Diversity Sequence [Postamble]

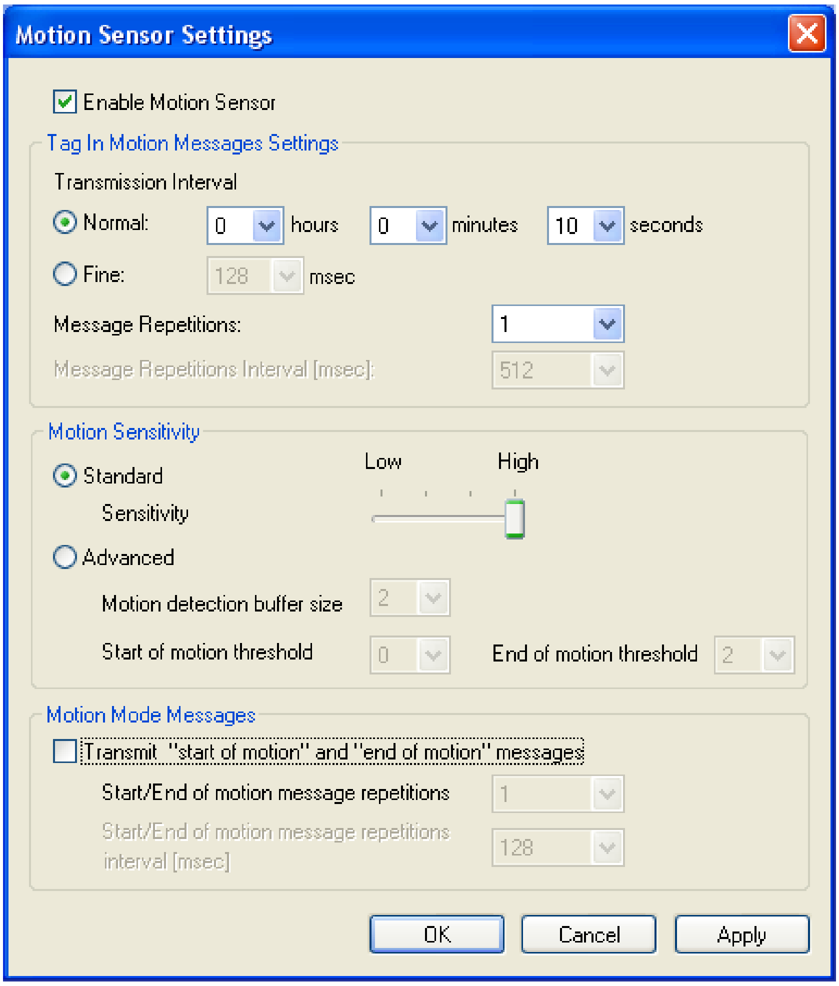
Destination Address for the transmission of Tag location messages: 01 0C CC 00 00 00

Data Frame Format: WDS

Serial Interface Configuration

Serial Baud Rate (bps): 19200

Figure B.7: Configuring a tag transmission power



Motion Sensor Settings

☑ Enable Motion Sensor

Tag In Motion Messages Settings

Transmission Interval

● Normal: 0 hours 0 minutes 10 seconds

○ Fine: 128 msec

Message Repetitions: 1

Message Repetitions Interval [msec]: 512

Motion Sensitivity

● Standard

Sensitivity (Low – High): High

○ Advanced

Motion detection buffer size 2

Start of motion threshold 0

End of motion threshold 2

Motion Mode Messages

☐ Transmit "start of motion" and "end of motion" messages

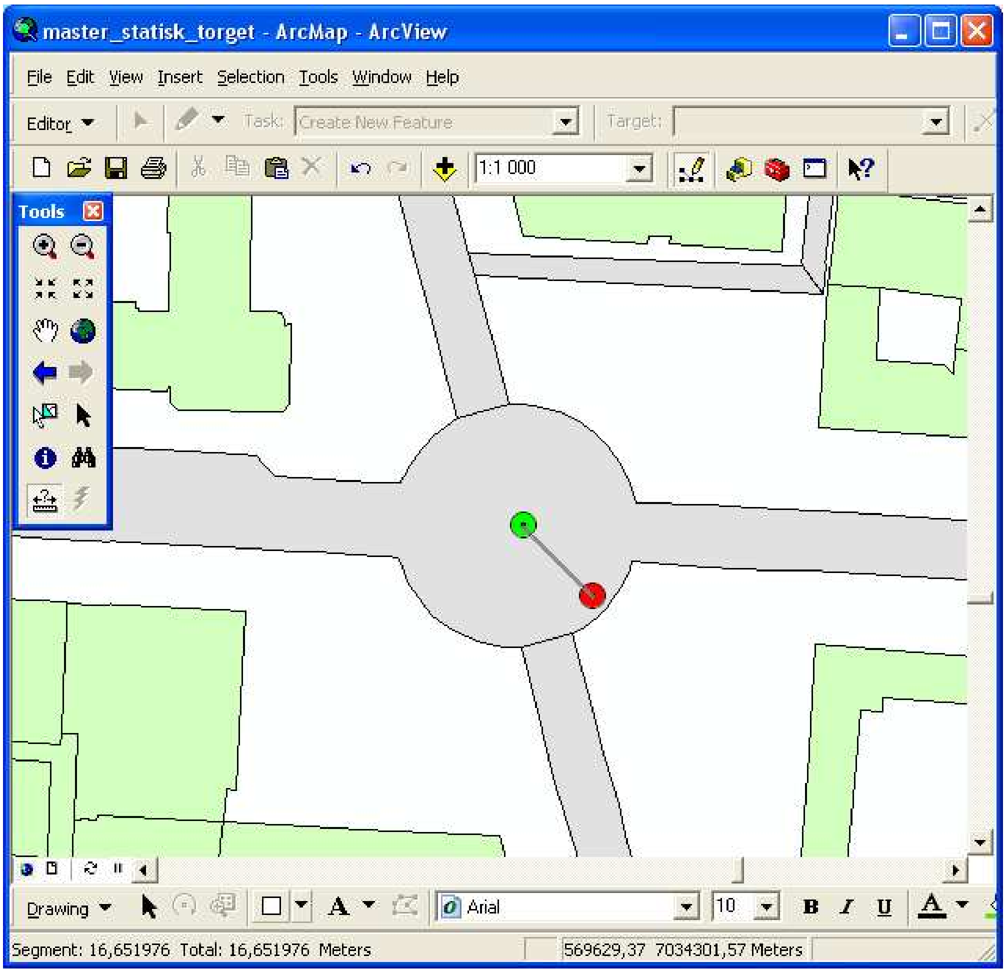
Start/End of motion message repetitions 1

Start/End of motion message repetitions interval [msec] 128

Figure B.8: Configuring the tag motion sensor

B.5 Computing Distance in ArcMap

ArcMap is used for comparing the computed tag locations with real-life locations. Figure B.9 illustrates how the distance between two points are computed in ArcMap. A line is drawn between the two points, and the distance between the points is shown in the lower left corner of the program window.



Segment: 16,651976 Total: 16,651976 Meters

569629,37 7034301,57 Meters

Figure B.9: Computing distance between to points in ArcMap. The distance in meter is shown in the lower left corner.

Appendix C

Other Wi-Fi RFID Tag Specifications

C.1 AeroScout T3

Radio	IEEE 802.11b/g compliant (2.4GHz)
Transmission power	Up to +19dBm (81mW)
Range	Up to 200m outdoor. Up to 60m indoor
Power	3.6V Lithium
Dimensions	74mm x 50mm x 10mm

Figure C.1: The AeroScout T3 tag. Figure and specifications are from [2]

C.2 PanGo V2

Radio	IEEE 802.11b/g compliant (2.4GHz)
Transmission power	Up to +16dBm
Range	N/A
Network Protocol	TCP/IP/DHCP
Security	WEP/WPA2
Power	3x 1.5V Lithium
Dimensions	64mm x 43mm x 23mm

Figure C.2: The Pango V2 tag. Figure and specifications are from [38]

C.3 PanGo V3

Radio	IEEE 802.11b/g compliant (2.4GHz)
Transmission power	N/A
Range	N/A
Network Protocol	TCP/IP/DHCP
Security	WEP/WPA2
Power	1.5V standard AA
Dimensions	49mm x 56mm x 23mm

Figure C.3: The Pango V3 tag. Figure and specifications are from [39]

C.4 Ekahau T201

Radio	IEEE 802.11b compliant (2.4GHz)
Transmission power	+14dBm
Range	Up to 150m outdoor. Up to 60m indoor
Network Protocol	TCP/IP/DHCP or static
Security	WEP 64/128 bit
Power	1800mAh Li-Ion rechargeable
Dimensions	49mm x 56mm x 23mm

Figure C.4: The Ekahau T201 tag. Figure and specifications are from [11]

C.5 Ekahau T301

Radio	IEEE 802.11b compliant (2.4GHz)
Transmission power	+18dBm
Range	Up to 100m outdoor. Up to 60m indoor.
Network Protocol	UDP/IP/DHCP or static
Security	WEP 64/128 bit
Power	2x CR2 Lithium
Dimensions	45mm x 55mm x 19mm

Figure C.5: The Ekahau T301 tag. Figure and specifications are from [12]

C.6 Radionor Cordis WLAN ID Transmitter

Radio	IEEE 802.11b compliant (2.4GHz)
Transmission power	N/A
Range	Up to 250m outdoor. Indoor N/A.
Power	2 mAh cell
Dimensions	20mm x 30mm

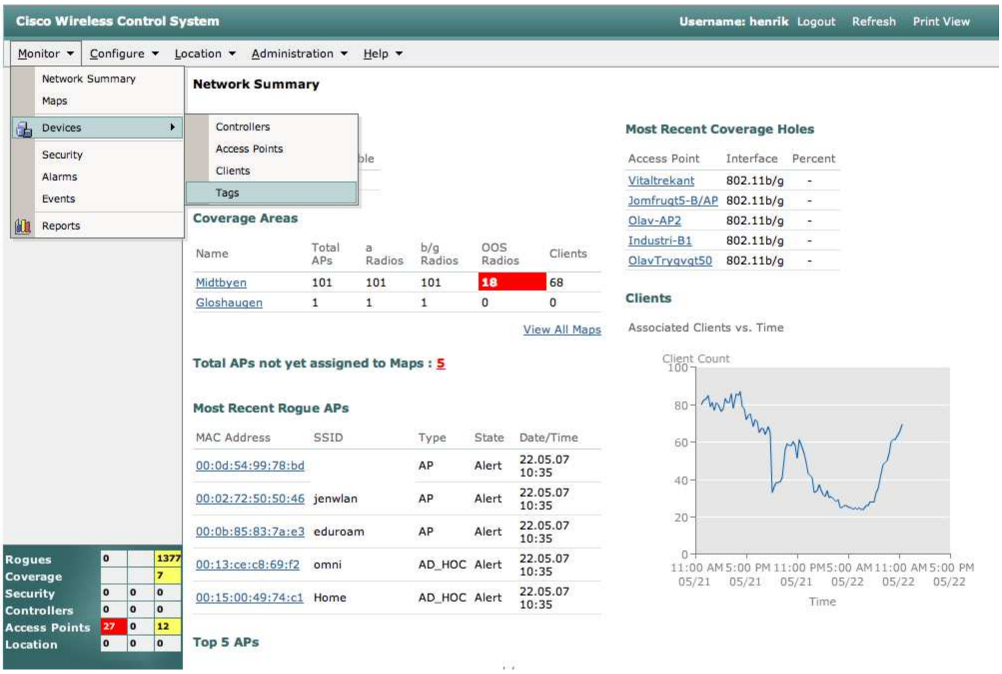
Figure C.6: The Radionor Cordis WLAN tag. Figure and specifications are from [41]

Appendix D

Cisco Wireless Control System

D.1 Monitoring Tag Locations

The tag location can be monitored through three different maps in WCS. All these maps are available from the drop-down menu shown in Figure D.1



Network Summary

Coverage Areas

Name	Total APs	a Radios	b/g Radios	OOS Radios	Clients
Midtbyen	101	101	101	18	68
Gloshaugen	1	1	1	0	0

Total APs not yet assigned to Maps : 5

Most Recent Rogue APs

MAC Address	SSID	Type	State	Date/Time
00:0d:54:99:78:bd		AP	Alert	22.05.07 10:35
00:02:72:50:50:46	jenwlan	AP	Alert	22.05.07 10:35
00:0b:85:83:7a:e3	eduroam	AP	Alert	22.05.07 10:35
00:13:ce:c8:69:f2	omni	AD_HOC	Alert	22.05.07 10:35
00:15:00:49:74:c1	Home	AD_HOC	Alert	22.05.07 10:35

Top 5 APs

Most Recent Coverage Holes

Access Point	Interface	Percent
Vitaltrekant	802.11b/g	-
Jomfrugt5-B/AP	802.11b/g	-
Olav-AP2	802.11b/g	-
Industri-B1	802.11b/g	-
OlavTrygvgt50	802.11b/g	-

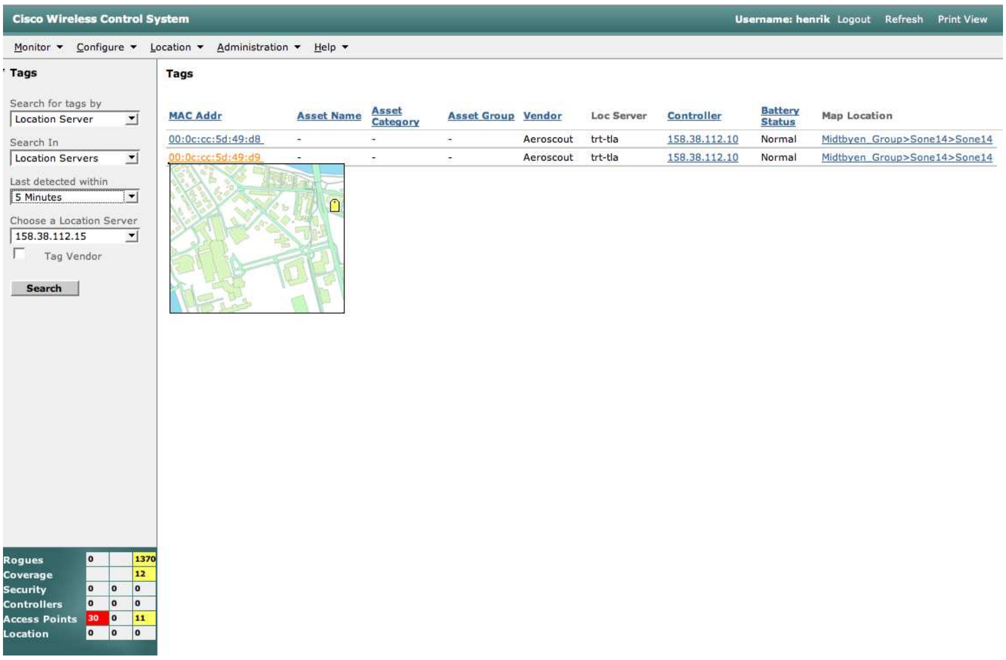
Clients

Associated Clients vs. Time

Rogues	0		1377
Coverage			7
Security	0	0	0
Controllers	0	0	0
Access Points	27	0	12
Location	0	0	0

Figure D.1: Tag monitoring in WCS.

The tags, which are currently located in the network are shown in the search result list as shown in D.2



Tags

Search for tags by: Location Server

Search In: Location Servers

Last detected within: 5 Minutes

Choose a Location Server: 158.38.112.15

☐ Tag Vendor

Tags

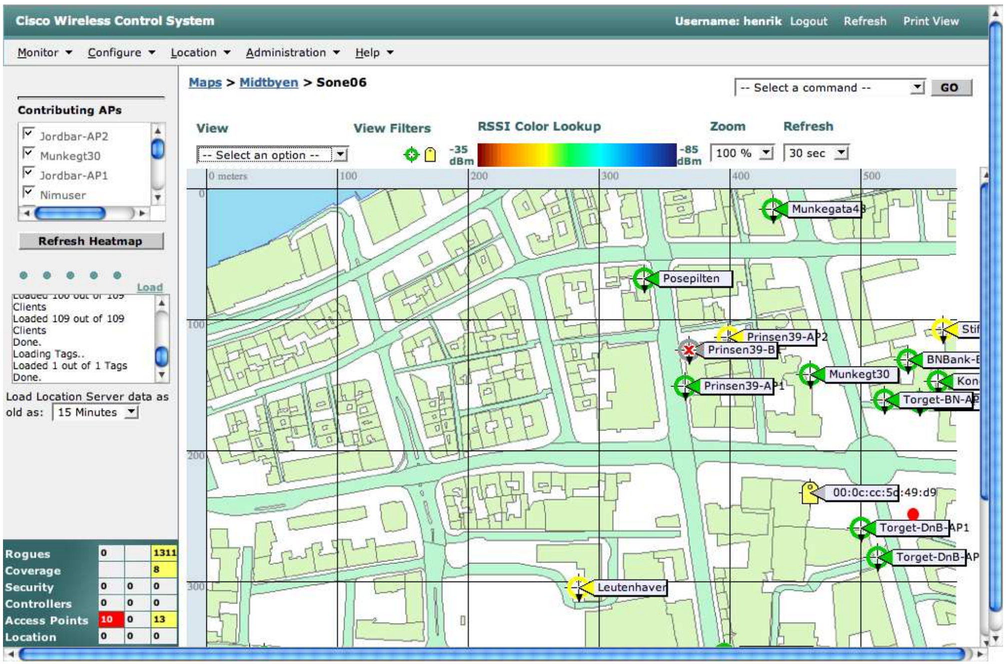
MAC Addr	Asset Name	Asset Category	Asset Group	Vendor	Loc Server	Controller	Battery Status	Map Location
00:0c:cc:5d:49:d8	-	-	-	Aeroscout	trt-tla	158.38.112.10	Normal	Midtbyen_Group>Sone14>Sone14
00:0c:cc:5d:49:d9	-	-	-	Aeroscout	trt-tla	158.38.112.10	Normal	Midtbyen_Group>Sone14>Sone14

Rogues	0		1370
Coverage			12
Security	0	0	0
Controllers	0	0	0
Access Points	30	0	11
Location	0	0	0

Figure D.2: WCS tag search results showing two located tags.

The tag location can be monitored in two maps, which use location information from the location server. These maps are illustrated in Figure D.3 and Figure D.4. There are differences in the computed locations in these two maps. The real-life tag location is illustrated with a small red circle in both figures.

The tag location can also be monitored through a third map, which uses location information directly from the WLAN controllers. This map is illustrated in D.5



☑ Jordbar-AP2
☑ Munkegt30
☑ Jordbar-AP1
☑ Nimuser

Loaded 100 out of 109 Clients
Loaded 109 out of 109 Clients
Done.
Loading Tags..
Loaded 1 out of 1 Tags
Done.

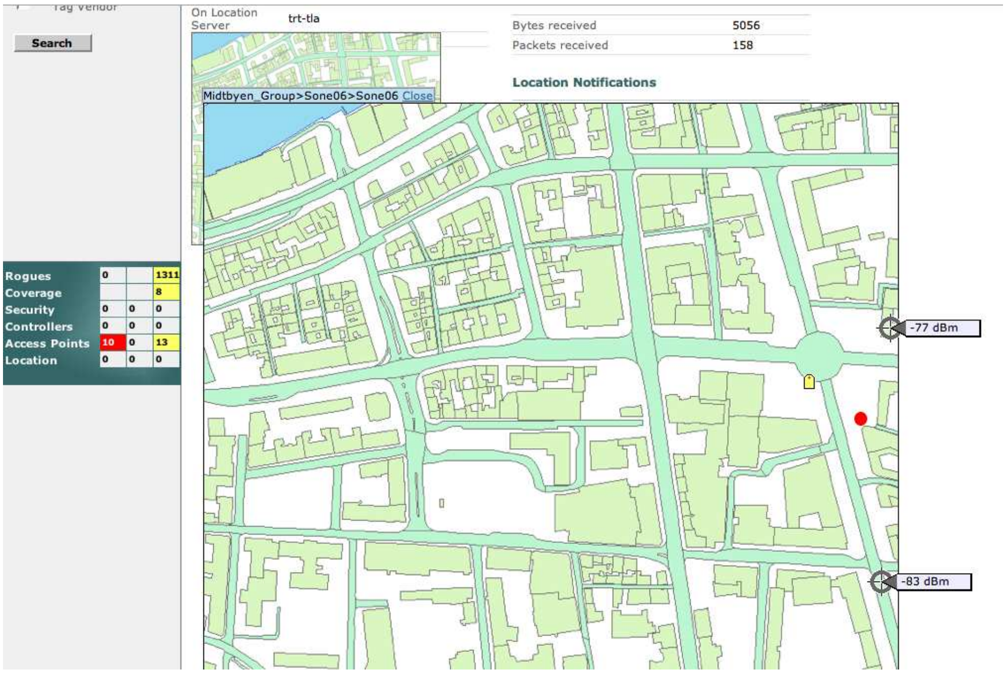
Load Location Server data as old as: 15 Minutes

Zoom: 100 %

Refresh: 30 sec

Rogues	0		1311
Coverage			8
Security	0	0	0
Controllers	0	0	0
Access Points	10	0	13
Location	0	0	0

Figure D.3: WCS general monitoring map. The map is generated based on information from the location server.



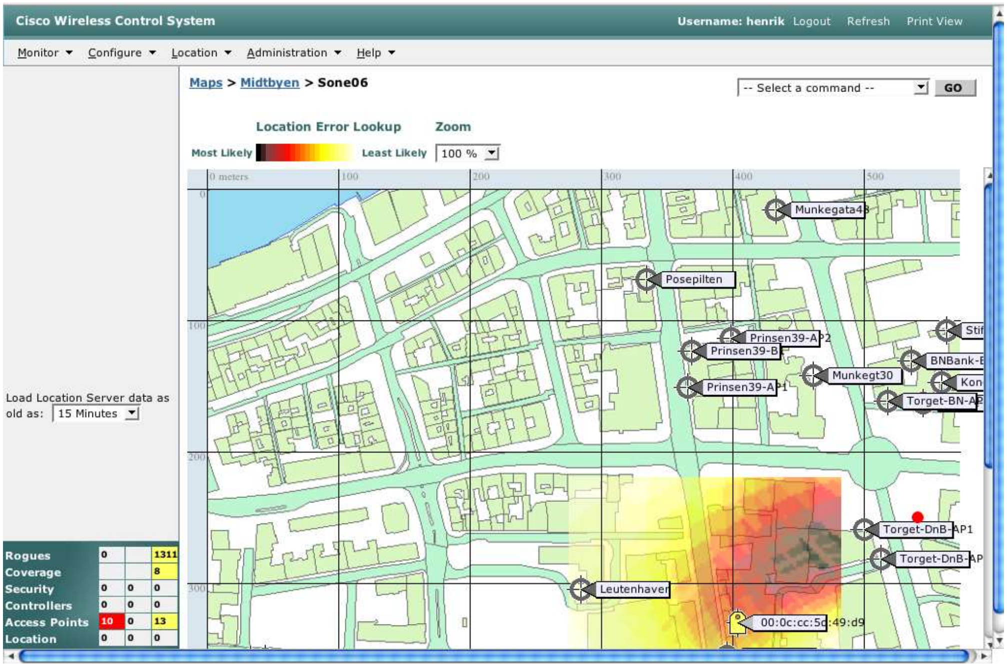
On Location Server: trt-tla

Bytes received: 5056

Packets received: 158

Rogues	0		1311
Coverage			8
Security	0	0	0
Controllers	0	0	0
Access Points	10	0	13
Location	0	0	0

Figure D.4: WCS map with detailed tag location. The map is generated based on information from the location server.



Username: henrik

Zoom: 100 %

Load Location Server data as old as: 15 Minutes

Rogues	0		1311
Coverage			8
Security	0	0	0
Controllers	0	0	0
Access Points	10	0	13
Location	0	0	0

Figure D.5: WCS map based on information from the controllers.

Appendix E

802.11 frame control

There exist three major 802.11 frame types. Data frames contain the information that is being transmitted from station to station. Control frames are used in the delivery of data frames between stations, to control the access to the medium and for sending acknowledgements. Management frames are used when stations are joining and leaving the wireless network and when associating to access points [13].

Table E.1 shows the use of address fields in data frames. The ToDS and FromDS fields determine whether the frame shall be delivered to the distribution system or within the IBSS. The former is possible using the WDS function, which connect several LANs wirelessly at the link layer [13].

DA (Destination Address), SA (Source Address), TA (Transmitter Address), RA (Receiver Address)

Funciton	*ToDS*	*FromDS*	*Address 1 (receiver)*	*Address 2 (transmitter)*	*Address 3 (filtering)*	*Address 4*
IBSS	0	0	DA	SA	BSSID	Not used
To AP	0	1	BSSID	SA	DA	Not used
From AP (infra)	1	0	DA	BSSID	SA	Not used
WDS (bridge)	1	1	RA	TA	DA	SA

Table E.1: Use of address fields in 802.11 data frames, from [13]

Appendix F

Electronic Attachments

The electronic attachments to this Master's thesis are available through a regular browser by opening the index.html file. Links to the different attachments are available from that web page.

Appendix G

Test results

G.1 Static Outdoor Location

Figure G.1: The results from the second static location test at Marinen. The computed locations are all approximately equal and close to the access point. The real-life location is denoted by the green cicle. The access point is represented by the black circle

G.2 Dynamic Outdoor Location

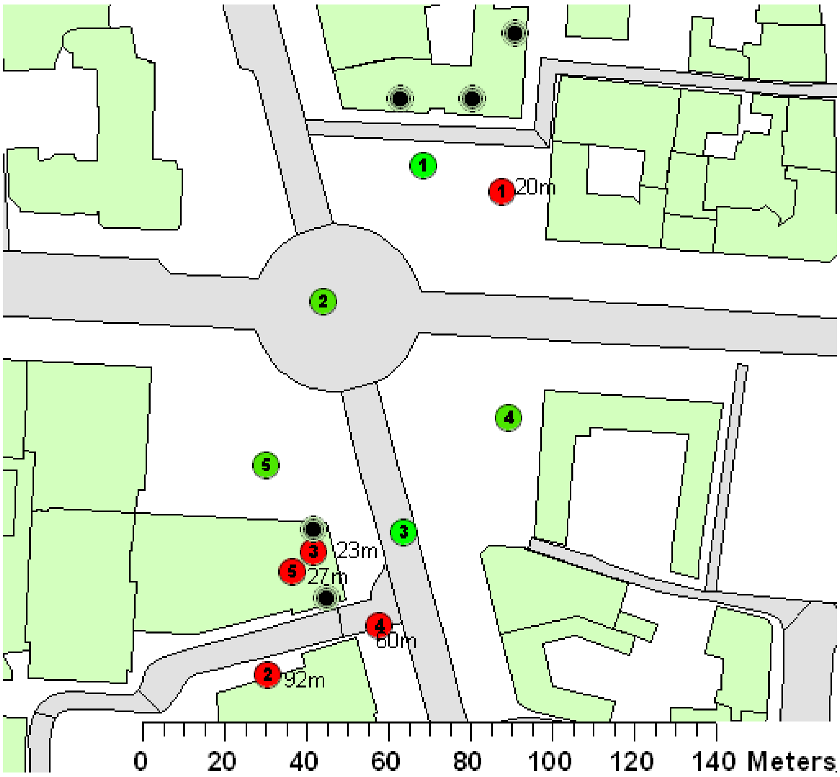


Figure G.2: The results from the dynamic location test at Torget. Green circles indicate actual location. Red circles indicate computed locations. Equal numbers denote each of the five locations. Black circles represents access points.

G.3 Computed Location Coordinates

The next ten pages contain the detailed location coordinates used when plotting the figures in the report. The coordinates are recorded from GeoPos and the GPS receiver.

Results, Static Outdoor Location Test Scenario

Location: Marinen, bench

GPS:	Longitude	10.396647	**Translated to UTM:**	Longitude	569709.0405242969
	Latitude	63.425057		Latitude	7033709.159134018

Date/time	**GeoPos coordinates**		**AP RSSI (dBm)**				**Error**	**Comments**
	Longitude	*Latitude*	*MarinenII*	*Samfundet-AP1*			*Distance in meters*	*Not within 100m*
07-06-07								
0831	569798	7033745	-86				99	
0832	569793	7033742	-88				94	
0833	569813	7033750	-87				116	x
0834	569794	7033743	-87				94	
0835	569793	7033742	-88				94	
0836	569793	7033741	-89				93	
0837	569616	7033416		-89			307	x
0838	569635	7033424		-88			295	x
0839	569642	7033427		-88			290	x
0840	569819	7033752	-88				121	x
				Average error in this test run			**160,3**	
07-06-07								
0903	569793	7033743	-87				94	
0904	569793	7033743	-87				94	
0905	569793	7033743	-87				94	
0906	569793	7033743	-87				94	
0907	569793	7033743	-87				94	
0908	569793	7033742	-88				94	
0909	569793	7033743	-87				94	
0910	569793	7033743	-87				94	

0911	569793	7033743	-87				94	
0912	569793	7033742	-88				94	
				Average error in this test run			**94,0**	
07-06-07								
0927	569793	7033745	-86				94	
0928	569793	7033743	-87				94	
0929	569793	7033744	-86				94	
0930	569793	7033744	-86				94	
0931	569793	7033743	-87				94	
0932	569793	7033743	-87				94	
0933	569793	7033743	-87				94	
0934	569793	7033743	-87				94	
0935	569793	7033741	-89				94	
0936	569793	7033742	-88				94	
				Average error in this test run			**94,0**	

Average error in the test	**116,10**
100m precision	83 %

Results, Static Outdoor Location Test Scenario

Location: Torget, statue outside the tourist office

GPS:	Longitude	10.395770	**Translated to UTM:**	Longitude	569653.2657474305
	Latitude	63.430003		Latitude	7034259.209278136

Date/time	**GeoPos coordinates**		**AP RSSI (dBm)**				**Error**	**Comments**	
	Longitude	*Latitude*	*Torget-BN-AP2*	*Torget-BN-AP1*	*Torget-DnB-AP1*	*Kongensgt16*	*Distance in meters*	*Not within 30m*	*Not within 50m*
03-05-07									
1225	569618	7034244	-84	-71	-67		38	x	
1226	569618	7034244	-82	-72	-68		38	x	
1227	569616	7034236	-84	-72	-67		44	x	
1228	569619	7034243	-83	-71	-68		38	x	
1229	569615	7034241	-82	-72	-68		42	x	
1230	569614	7034241	-82	-71	-67		43	x	
1231	569616	7034238	-82	-73	-67		43	x	
1232	569616	7034241	-83	-71	-67		42	x	
1233	569619	7034243	-84	-71	-68		38	x	
1234	569618	7034245	-82	-71	-68		38	x	
				Average error in this test run			**40,4**		
07-05-07									
1125	569628	7034236	-85	-72	-66		34	x	
1126	569629	7034238	-85	-72	-66		33	x	
1127	569604	7034212	-87	-74	-66	-93	68	x	x
1128	569599	7034209	-88	-72	-66	-93	75	x	x
1129	569597	7034208	-87	-71	-65	-94	77	x	x
1130	569596	7034201	-89	-73	-65	-94	82	x	x
1131	569595	7034199	-88	-75	-66	-94	83	x	x
1132	569597	7034208	-86	-72	-66	-94	84	x	x

1133	569596	7034197	-90	-75	-66	-94	85	x	x
1134	569597	7034207	-88	-72	-67	-94	76	x	x
				Average error in this test run			**69,7**		
07-05-07									
1550	569619	7034251	-80	-69	-66		36	x	
1551	569608	7034243	-79	-69	-66		48	x	
1552	569599	7034237	-80	-69	-67	-90	59	x	x
1553	569620	7034256	-80	-69	-66		33	x	
1554	569621	7034254	-81	-68	-65		33	x	
1555	569622	7034254	-81	-68	-65		32	x	
1556	569602	7034238	-80	-68	-66	-95	55	x	x
1557	569592	7034224	-81	-70	-66	-97	71	x	x
1558	569594	7034230	-80	-69	-66	-97	66	x	x
1559	569619	7034256	-79	-69	-66		33	x	
				Average error in this test run			**46,6**		

Average error in the test	**52,23**
30m precision	0 %
50m precision	60 %
Total static average	40,55

Results, Static Indoor Location Test Scenario

Location: Solsiden shopping center, Clas Ohlson entrance

UTM:	Longitude	569653.2657474305
	Latitude	7034259.209278136

Date/time	**GeoPos coordinates**		**AP RSSI (dBm)**			**Error**	**Comments**	
	Longitude	*Latitude*	*Solsiden-AP3*	*Solsiden-AP1*	*Krana*	*Distance in meters*	*Not within 10m*	Not within 30m
07-05-07								
1256	570443	7034826	-61	-74	-72	19	x	
1257	570437	7034834	-61			18	x	
1258	570423	7034848	-60	-86		2		
1259	570421	7034850	-60	-90		4		
1300	570442	7034827	-60	-90		27	x	
1301	570427	7034844	-59	-90		5		
1302	570425	7034847	-58	-89		2		
1303	570422	7034849	-61	-89		2		
1304	570421	7034850	-62	-89		4		
1305	570442	7034821	-61	-72	-72	32	x	x

Average error in the test	**11,50**
10m precision	60 %
30m precision	90 %

Results, Dynamic Outdoor Location Test Scenario

Location: Solsiden, 10 arbitrary locations

Location ID	Approx. UTM coordinates		GeoPos coordinates		Error distance (m)	
	x	y	x	y		
1	570287	7034872	570479	7034717	247	
2	570316	7034851	570324	7034848	9	
3	570394	7034803	570357	7034815	38	
4	570441	7034746	570448	7034742	9	
5	570468	7034755	570474	7034750	9	
6	570417	7034792	570398	7034788	20	
7	570336	7034837	570329	7034843	10	
8	570409	7034802	570378	7034801	32	
9	570464	7034776	570437	7034790	31	
10	570496	7034734	570442	7034804	88	
			Average error distance (m)		**49,3**	

Location: Torget

Location ID	Appro		Translated to UTM		GeoPos coordinates		Error distance (m)	
	Longitude	Latitude	x	y	x	y		
1	10.394815	63.430422	569604.5973	7034304.8494	569657	7034342	20	
2	10.395	63.430512	569613.6098	7034315.0768	569600	7034224	92	
3	10.395097	63.430143	569619.3452	7034274.0742	569611	7034254	23	
4	10.395893	63.430247	569658.8106	7034286.5256	569627	7034236	60	
5	10.3947	63.430155	569599.5070	7034274.9796	569606	7034249	27	
					Average error distance (m)		**44,4**	

Results, Static Outdoor Location Test Scenario

Location: Marinen, stone fence

GPS:	Longitude	10.397387	**Translated to UTM:**	Longitude	569746.8433332866
	Latitude	63.424698		Latitude	7033669.970608678

Date/time	**GeoPos coordinates**		**AP RSSI (dBm)**				**Error**	**Comments**
	Longitude	*Latitude*	*MarinenII*	*Samfundet-AP1*			*Distance in meters*	*Not within 100m*
07-06-07								
0844	569794	7033748	-74				92	
0845	569793	7033748	-73				91	
0846	569793	7033748	-74				91	
0847	569793	7033748	-74				91	
0848	569793	7033748	-73				91	
0849	569793	7033748	-73				91	
0850	569793	7033748	-72				91	
0851	569793	7033748	-72				91	
0852	569793	7033748	-72				91	
0853	569793	7033749	-71				92	
				Average error in this test run			**91,2**	
07-06-07								
0903	569793	7033748	-74				91	
0904	569793	7033748	-74				91	
0905	569793	7033748	-74				91	
0906	569793	7033748	-73				91	
0907	569793	7033748	-74				91	
0908	569793	7033748	-73				91	
0909	569793	7033748	-74				91	
0910	569793	7033748	-72				91	

0911	569793	7033748	-73				91	
0912	569793	7033748	-72				91	
				Average error in this test run			**91,0**	
07-06-07								
0937	569793	7033747	-75				90	
0938	569793	7033747	-75				90	
0939	569793	7033748	-74				91	
0940	569793	7033748	-73				91	
0941	569793	7033748	-73				91	
0942	569793	7033748	-73				91	
0943	569793	7033748	-73				91	
0944	569793	7033748	-73				91	
0945	569793	7033747	-75				90	
0946	569793	7033748	-73				91	
				Average error in this test run			**90,7**	

Average error in the test	**90,97**
100m precision	100 %

Results, Static Outdoor Location Test Scenario

Location: Torget, left edge of the scene

GPS:	Longitude	10.395497	**Translated to UTM:**	Longitude	569637.697130306
	Latitude	63.430805		Latitude	7034348.258503777

Date/time	**GeoPos coordinates**		**AP RSSI (dBm)**				**Error**	**Comments**	
	Longitude	*Latitude*	*Torget-BN-AP2*	*Torget-BN-AP1*	*Torget-DnB-AP1*	*Kongensgt16*	*Distance in meters*	*Not within 30m*	Not within 50m
03-05-07									
1201	569662	7034345	-71	-57	-68		24		
1202	569661	7034345	-72	-58	-68		24		
1203	569660	7034346	-70	-59	-68		23		
1204	569663	7034348	-71	-59	-70		26		
1205	569629	7034312	-70	-59	-69	-84	37	x	
1206	569623	7034307	-70	-59	-69	-86	44	x	
1207	569623	7034306	-71	-59	-69	-86	45	x	
1208	569622	7034313	-70	-58	-70	-87	44	x	
1209	569625	7034314	-71	-59	-70	-85	36	x	
1210	569626	7034321	-70	-58	-71	-85	30		
				Average error in this test run			**33,3**		
07-05-07									
1113	569672	7034339	-75	-61	-68		36	x	
1114	569665	7034342	-74	-61	-69		28		
1115	569554	7034340	-74	-60	-68		84	x	x
1116	569665	7034340	-75	-60	-68		28		
1117	569655	7034323	-75	-60	-65	-81	31	x	
1118	569661	7034332	-76	-60	-66		29		
1119	569662	7034333	-75	-59	-66		29		
1120	569661	7034331	-75	-59	-66		29		

1121	569663	7034335	-76	-60	-65		29		
1122	569663	7034335	-76	-60	-65		29		
				Average error in this test run			**35,2**		
07-05-07									
1536	569645	7034333	-80	-61	-70		17		
1537	569642	7034333	-78	-56	-68		16		
1538	569641	7034332	-77	-56	-64		16		
1539	569641	7034331	-78	-55	-64		16		
1540	569642	7034332	-78	-55	-65		17		
1541	569641	7034331	-79	-55	-64		17		
1542	569640	7034330	-79	-55	-63		19		
1543	569641	7034331	-78	-55	-64		18		
1544	569641	7034331	-79	-55	-64		18		
1545	569640	7034283	-79	-55	-63	-82	66	x	x
				Average error in this test run			**22,0**		

Average error in the test	**30,17**
30m precision	70 %
50m precision	93 %