Air Interface Specification

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ABB Corporate Research

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Summary

This document specifies the Air Interface for a wireless sensor and actuator system. This specification has to be met by all base station, sensor and actuator versions that should be able to interoperate.

It does not specify the powering of the sensors and actuators.

The physical layer and the lower part of the link layer is described here. The document “WISA Profile Specification” 12 describes the data link layer and control link layer. (The content of 12 was part of this document up to and including version 1.10.)

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Abbreviations

Abbr.	Explanation
BS	Base Station
BT	Bandwidth Time product
CCH	Control Channel
C	Control bit(s) in the messages
Cell	Area where the Sensors/Actuators is controlled by the same down link
Cell_ID	Cell Identity
c_i	Inner sequence number
c_o	Outer sequence number
DCH	Data Channel
DL	Down link, RF link from base station to SA
DN	Dslot Number assigned to the SA's for down link reception
Dslot	Double slot, slot structure of the frame on the down link
FDD	Frequency Division Duplex
FEC	Forward Error Control, used for correcting (transmission) errors
FH	Frequency Hopping
FN	Frame Number
FSK	Frequency Shift keying
IMA	I'm Alive message
ISM	Industrial, Scientific and Medical frequency band
K	Uplink group number
MSC	Message Sequence Chart
n_B	Number of non-overlapping frequency sub bands
n_I	Number of frequencies in each non-overlapping frequency sub band
PL	Pay Load is the information part of the messages (profile dependent)
PLC	Programmable Logic Controller
PLN	Pay Load Number assigned to SA's for extracting correct part of PL
RSSI	Receiver Signal Strength Indicator
SA	Sensor/Actuator
SA_no	Sensor/Actuator identity number
Slot	Slot structure of the frame on the up link
T	Time, length of period
TDMA	Time Division Multiple Access
TN	Transmission Number assigned to SA's for the up link transmission
Tx/Rx	Transmit/Receive
UL	Up Link, RF link from SA to base station
W	Sub band hopping sequences
X	Index hopping sequence

1 Introduction

This document specifies the Air Interface for a wireless sensor and actuator system. This document will not specify the powering of the SA's, which can also be done wireless, nor will it specify the interface between the Base Station and the PLC, see Figure 1.

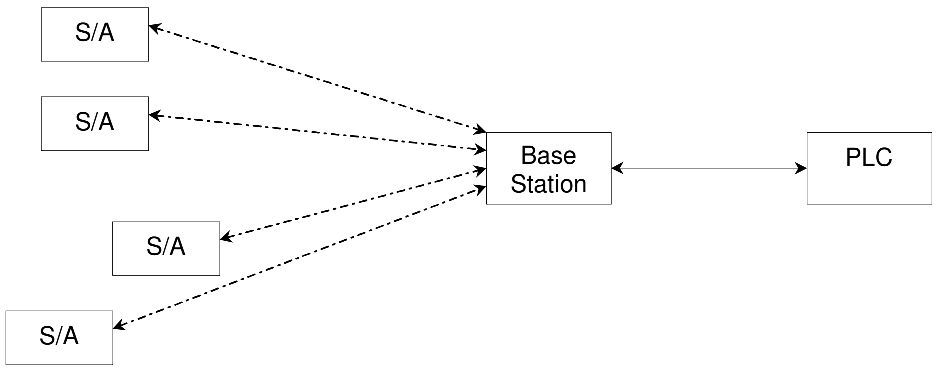

Figure 1: SA block diagram

A Base Station is in control of a group of SA's using a wireless channel. The radio channel from the BS to the SA is called the Down Link and the channel from the SA to the BS is called the Up Link. SA's using the same Down Link channel are said to be in the same RF cell, see Figure 2. The cells can be spatially overlapping and frequency hopping with frequency reuse is used. One Base Station can be in charge of more than one cell.

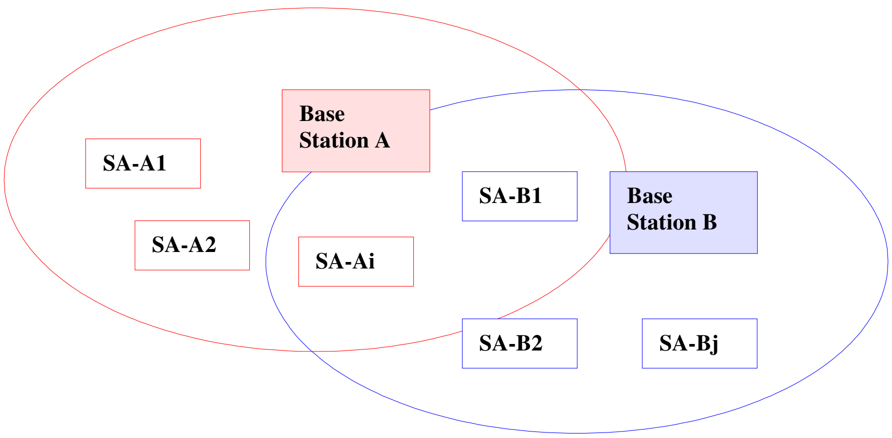

Figure 2: Cell architecture

The wireless sensor and actuator system is using the Industrial, Scientific and Medical (ISM) 2.4 GHz frequency band. This frequency band is open for many different types of equipment as well as different applications. To reduce the effect of interference as well as multi-path fading the system will rely on frequency hopping and optionally space diversity (antenna diversity).

2Protocol Stack Overview

The black part of Figure 3 shows the part of the protocol stack that will be specified in this document.

The protocol stack is not symmetrical, i.e. the stack in the base station is not the same as in the SA. The control plane and the data plane are multiplexed onto the same physical link. The Control Channel (CCH) and Data Channel (DCH) are both parts of the Up and Down Link.

One RF cell can concurrently operate more than one profile, i.e. applications of different types can be operating in the same cell.

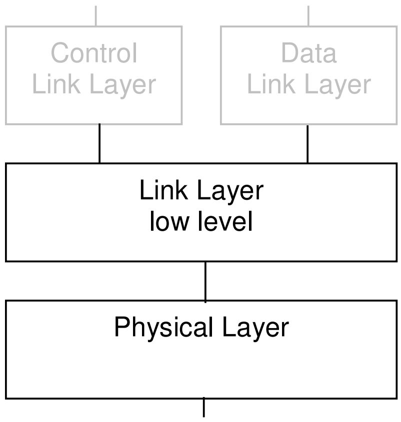

Figure 3: Protocol stack

The low level of the Link Layer and the Physical Layer will be common for all the different applications. The physical layer is specified in section 3, 4, 5 and 9 and the lower part of the link layer is specified in section 6, 7, and 8.

Configuration of nodes is described in section 10. Strictly, this is on the high level of the link layer, but is included here because it is common to all profiles.

The majority of the Control and Data Link Layer (grey color) will be specific to the device types and will be specified in individual profiles. See the WISA Profile Specification 12.

The interfaces between the layers are not specified, only the protocols. Note there is no network layer.

3Modulation

The radio frequency characteristics for the SA's are identical to those of Bluetooth, see ref. 12. The BS radio frequency characteristics are in some areas more complicated.

The data transmitted has a bit rate of $1/T_b$ = 1 Mb/s both uplink and downlink.

A Gaussian-shaped, binary FSK modulation is applied with a BT product of 0.5. Modulation index is between 0.28 and 0.35, corresponding to a frequency deviation of 140 kHz to 175 kHz.

Up- and downlink are separated in frequency: frequency division duplex (FDD).

The carrier frequency f_c for the uplink and downlink are given by a channel number n, $f_c = f_0 + n * 1$ MHz (same channel separation as for Bluetooth), where $f_0 = 2402$ MHz and n=0..78.

4Radiation

The Base Station and the sensors/actuators shall comply with the FCC ref. 12 and the EN 300 328 ref.12 for the use of the 2.4 GHz ISM frequency band.

The transmission power is nominally 0 dBm.

The sensitivity of the receivers should be –80 dBm or better.

5Antenna switching

The Base Station can be equipped with multiple Rx/Tx antennas. Multiple antennas will lessen the problem with multi-path fading and shadowing. The use of multiple antennas is optional and shall be specified in the profile for the application.

It is assumed that antenna switching can be implemented without causing significant Rx/Tx transients. The antenna switching shall be co-ordinated with the frequency hopping, see section 9, i.e. done at frame boundaries.

6Media Access

The overall structure of the frame format will be fixed, but the use and details will be specified in individual profiles. I.e. the contents of the frame and the protocol is different for sensors and actuators and there can be multiple profiles for SA's, see 12.

The medium access is time division multiple access TDMA/FDD/FH. Different formats are used in the uplink and downlink

The downlink – base station to sensor/actuator – transmission is always on (but hop in frequency, see section 9), for the purpose of establishing frame and slot synchronisation for the SA's. It will enable the sensors/actuator to find its own time slot where it is allowed to transmit its uplink message.

The uplink – sensor/actuator to base station - will normally be off most of the time.

The frame format allows up to 120 sensors/actuators per cell (with 4 uplink groups, see 6.1 below), which are sampled every 2048µs. It is possible to support more than 120 sensors by running multiple cells/systems in parallel, at different frequencies.

- The TDMA frame length is T_{frame} = Slots*T_{Slot} = 32*64µs = 2048µs.
- A downlink frame is divided into 16 Dslots. Each Dslot lasts 128 µs and contains slot number and payload for 8 sensor/actuators. For detailed frame format see section 7.
- Uplink frames are aligned to downlink frames. There are 32 uplink slots per frame. Each slot lasts 64 µs. Each sensor/actuator may transmit an uplink burst in at most one slot per frame. An uplink burst contains the data from this sensor/actuator. For detailed slot format information see section 8.
- The uplink frames can also support double slots giving increased capacity in this direction also. There are 16 Dslots each lasting 128 µs. The start of the uplink Dslots is identical to the single slot. Each sensor/actuator may transmit an uplink burst in at most one slot per frame. An uplink burst contains the data from this sensor/actuator. For detailed slot format information see section 8. The start of the uplink Dslot can only start at even TN numbers see Figure 4. The SA number will be the corresponding SA number to the start of the Dslot.
- In order to support 120 sensor/actuators per cell each sensor/actuator is part of one of four uplink groups {UL_0, UL_1, UL_2, UL_3}. Each uplink group use separate frequencies (FDMA), which are different from the downlink frequency (FDD). These 5 frequencies will hop on a per frame basis, see section 9.
- A sensor/actuator transmitting in a certain uplink slot assigned to it, must read the downlink Dslot delayed by **3** Dslots for the BS acknowledgement. This staggering allows for at least 256 µs TX/RX-turnaround time, see Figure 4 and Figure 10.
- The sensor/actuators assigned to transmit in slot TN=24 or later in frame number FN, must tune to the downlink frequency of frame FN + 1 for receiving the acknowledgement, see Figure 4 and Figure 10.

Due to limited cross talk protection between different UL groups and that there is a lot of bit communality between the start of Dslot and the single slot it is advisable to run a Hamming distance check between each correct received single slot and the corresponding received bits in the Dslot. If the Hamming distance is less than 4 the single slot message should be discarded requiring a retransmission. An alternative is to not configure the Base Station with single slot devices in the employed uplink Dslots.

.6.1SA numbering scheme

The number of uplink groups (number of concurrent uplink frequencies) is denoted as K.; $1 \le K \le n_l$ (where n_l is defined in Section 9). The default value is K = 4.

A cell supports up to K·30 = 120 sensor/actuators. A sensor/actuator for a given cell is assigned a sensor/actuator number SA_no, with SA_no ∈ [0 .. K·30-1] = [0 .. 119].

For the uplink, the sensor/actuator is assigned an uplink slot number TN or, if it needs a double slot, a pair of TN's. Note that TN ∈ [0 .. 31] for any K. The mapping is chosen such that the first half of the sensor/actuators use only every second time slot, thus allowing a guard time of one uplink slot, i.e. 64µs. The uplink group is

UL = (SA_no mod K), for K=4.

There are K = 4 uplink groups UL ∈ $\{UL_0 .. UL_{K-1}\} = \{UL_0, UL_1, UL_2, UL_3\}$, see Figure 4.

For the downlink, the sensor/actuator is assigned for reception to the downlink Dslot number DN,

For any K, DN ∈ [0 .. 15]. Within the given Dslot, the payload part number PLN is assigned to a particular sensor/actuator, with PLN ∈ [0 .. 2K-1] = [0 .. 7], see Figure 4 and Table 1.

TN	0	1	2	3	4	5	6	7	…	24	25	26	27	28	29	30	31
UL0	0	60	4	64	8	68	12	72		48	108	52	112	56	116		
UL1	1	61	5	65	9	69	13	73		49	109	53	113	57	117		
UL2	2	62	6	66	10	70	14	74		50	110	54	114	58	118		
UL3	3	63	7	67	11	71	15	75		51	111	55	115	59	119		
DN PLN	0 0 1 2 3 4 5 6 7		1 0 1 2 3 4 5 6 7		2 0 1 2 3 4 5 6 7		3 0 1 2 3 4 5 6 7			12 0 1 2 3 4 5 6 7		13 0 1 2 3 4 5 6 7		14 0 1 2 3 4 5 6 7		15	
ACK	48 … 51 108 … 111		52 … 55 112 … 115		56 … 59 116 … 119		0 … 3 60 … 63			36 … 39 96 … 99		40 … 43 100 … 103		44 … 47 104 … 107			

Figure 4: SA numbering and mapping scheme K=4

The unshaded numbers are the SA_no's. Note that TN 30 and 31 and DN 15 is used for switching the frequencies as part of the frequency hopping scheme, see section 9.

Another way of depicting the SA numbers on the air interface is Table 1. Downlink ACK, as well as commands and data to a given SA, may be transmitted in the third Dslot after the SA's designated uplink Dslot.

Table 1: Single- and double-slots vs. SA numbers; Uplink and downlink

TN = Sslot	Uplink group			
	UL0	UL1	UL2	UL3
	SA number			
0	0	1	2	3
1	60	61	62	63
2	4	5	6	7
3	64	65	66	67
4	8	9	10	11
5	68	69	70	71
6	12	13	14	15
7	72	73	74	75
8	16	17	18	19
9	76	77	78	79
10	20	21	22	23
11	80	81	82	83
12	24	25	26	27
13	84	85	86	87
14	28	29	30	31
15	88	89	90	91
16	32	33	34	35
17	92	93	94	95
18	36	37	38	39
19	96	97	98	99
20	40	41	42	43
21	100	101	102	103
22	44	45	46	47
23	104	105	106	107
24	48	49	50	51
25	108	109	110	111
26	52	53	54	55
27	112	113	114	115
28	56	57	58	59
29	116	117	118	119
30				
31				

PLN = Payload part number = Downlink 'SA index'								DN = Dslot
0	1	2	3	4	5	6	7	
Downlink ACK etc. for SA numbers:								
48	49	50	51	108	109	110	111	0
52	53	54	55	112	113	114	115	1
56	57	58	59	116	117	118	119	2
0	1	2	3	60	61	62	63	3
4	5	6	7	64	65	66	67	4
8	9	10	11	68	69	70	71	5
12	13	14	15	72	73	74	75	6
16	17	18	19	76	77	78	79	7
20	21	22	23	80	81	82	83	8
24	25	26	27	84	85	86	87	9
28	29	30	31	88	89	90	91	10
32	33	34	35	92	93	94	95	11
36	37	38	39	96	97	98	99	12
40	41	42	43	100	101	102	103	13
44	45	46	47	104	105	106	107	14
								15

7Downlink Format

The downlink format is based on the concept of double slots and that there can be a maximum of 120 SA's and the single slot length is 64 bits. The double slot will be 128 bits long. The double slot is a compromise between the efficiency of the channel and how often the sensor/actuator can synchronise to the downlink. The payload (PL) is profile dependent. The PL, Control, Dslot and CRC are transmitted twice resulting in a product code.

The optional use of Forward Error Correction (FEC) shall be specified in the profiles.

The cell Id is 8 bit long.

The numbers in Figure 5 are the number of bits allocated.

Preamble 24	Cell ID 8	PL 32	C 4	Dslot 4	CRC 8	PL 32	C 4	Dslot 4	CRC 8

Figure 5: Product code encoded downlink message

The preamble is required for bit and slot synchronisation at the receivers.

Downlink sync preamble: s_{dl} = [0101 1001 1001 0100 0011 1110].

Since the Cell_ID is constant for a cell it can be used as a part of the synchronisation bit pattern after the SA has been configured.

The CRC shall be calculated over the Cell ID, payload, Control and Dslot Number. Note that the Cell ID is not repeated but is used in the calculation of both CRC's. The effect of the Cell ID on the CRC can be pre-calculated and only XORed in at the end of CRC calculation.

There is one spare bit in the CRC field placed in the MSB position. Note the CRC calculation shall include this spare bit.

The generator polynomial for the CRC is: $(x^6 + x^5 + x^2 + x + 1)(x + 1)$. The CRC shift register shall be pre-set to zero prior to the CRC calculation. The Hamming distance is 8 for the repeated message. The CRC field shall be inverted prior to transmission to detect false synchronisation.

The Control bits are used for distinguishing between data and control information, see 12 for further information.

Dslot is the current double slot number.

The MSB bit in each byte is transmitted first.

The message is scrambled by inverting the repeated part of the message (PL32, C4, Dslot4 and CRC8). Note that the CRC8 was inverted in the first place (due to synchronisation) will now be transmitted non-inverted.

8Uplink Format

The slot length is 64 bits and the double slot is 128 bits. There is a guard-time (GT) between adjacent slots.

The numbers in Figure 6 are the number of bits allocated.

Preamble 15	C 1	Cell ID 8	PL 8	CRC 8	PL 8	CRC 8	Guard 8

Figure 6: Product code encoded uplink message ('short' telegram)

Preamble 15	C 1	Cell ID 8	K 8	PL 32	CRC 8	K 8	PL 32	CRC 8	Guard 8

Figure 7: Product code encoded uplink Dslot message ('long' telegram)

Note: To protect against cross-talk between different UL-groups belonging to the same Cell ID, the UL-group number (two bits) are placed in the two MSB bits of the Cell ID parameter in the uplink message.

The preamble is required for bit and slot synchronisation at the receivers.

Uplink sync preamble: s_{ul} = [0101 0101 0001 101].

C is a control bit indicating if the payload is control information or data. C = 0 if the payload is data, see 12 for further information.

The CRC shall be calculated over the Control bit, Cell ID, (K command) and payload. The Control bit and the Cell ID are not repeated but are used in the calculation of both CRC's. The effect of the C bit and the Cell ID on the CRC can be pre-calculated and only XORed in at the end of CRC calculation.

There is one spare bit in the CRC field placed in the MSB position. Note the CRC calculation shall include this spare bit.

The generator polynomial for the CRC is: $(x^6 + x^5 + x^2 + x + 1)(x + 1)$. The CRC shift register shall be pre-set to zero prior to the CRC calculation. The Hamming distance is 8 for the repeated message. The CRC field shall be inverted prior to transmission to detect false synchronisation.

The SA_no shall be XOR'ed with the CRC prior to transmission to detect SA's transmitting in the wrong slot.

The MSB bit in each byte is transmitted first.

The message is scrambled by inverting the repeated part of the message ((K), PL and CRC). Note that the CRC was inverted in the first place (due to synchronisation) will now be transmitted non-inverted.

9Frequency Hopping

For background and motivation of Frequency Hopping FH, see ref. 12. The SA FH scheme has the following properties:

- Hopping is on a frame-by-frame basis, i.e. the dwell time equals the TDMA frame duration of 2048 μs.
- Re-transmissions occurring in consecutive frames are on different frequencies with wide separation (typically 20 MHz). The motivation is given in ref. 12.
- The hopping frequency set spans the available frequency band between 2400 MHz and 2480 MHz. In a given frame, uplink and downlink frequencies have wide separation (> 20 MHz).
- The hopping frequency is uniquely determined by (i) the frame number FN (counting cyclically), (ii) the cell_id, (iii) the transmission direction {DL, UL_0, UL_1, UL_2, UL_3}.
- Cross-correlation of hopping sequences for different cell_ids (within the set of allowable cell_ids) are low. Low cross correlation is relevant to reduce inter-cell interference ref. 12.

Details are given in the following section.

.9.1Definition of hopping sequences

FH sequences can be represented by periodic multilevel integer sequences. Construction of sets of periodic sequences with low cross-correlation is described in ref. 12. Here, this construction is applied in 2 stages (outer and inner), in order to enforce high separation of frequencies in consecutive frames:

The available frequency band is divided into $n_B = 7$ non-overlapping sub bands. Each sub band contains $n_I = 11$ frequencies, spaced 1 MHz apart. Therefore, a total of $7 \cdot 11$ MHz = 77 MHz is used out of the available 83.5 MHz. Figure 8 shows the generation of the hopping frequency, given the cyclically incremented frame number FN. The outer *sub band* hopping sequence $W_{co}(\cdot)$ determines the sub band, such that consecutive hop frequencies are in different sub bands. Within the selected sub band, the inner *index* hopping sequence $X_{ci}(\cdot)$ selects the actual frequency. For a given cell identity cell_id, where cell_id $\in$ [0 .. 59], these sequences are selected in a unique manner and determine the actual frequency hopping sequence.

Table 2: Sub band hopping sequences

$W_0(\cdot)$ = [	0	1	2	3	4	5	6	]
$W_1(\cdot)$ = [	0	2	4	6	1	3	5	]
$W_2(\cdot)$ = [	0	3	6	2	5	1	4	]
$W_3(\cdot)$ = [	0	4	1	5	2	6	3	]
$W_4(\cdot)$ = [	0	5	3	1	6	4	2	]
$W_5(\cdot)$ = [	0	6	5	4	3	2	1	]

There are 6 sequences $W_{co}(\cdot)$ of length 7 (n_B=7-ary), selected by c_o = (cell_id) div 10.

Note: These sequences are generated according to construction 2 of ref. 12 using the Galois field GF(7). A useful formula is $W_n(\cdot) = (W_0(\cdot)\cdot(n+1)) \bmod 7$, for n = 1 to 5.

Table 3: Index hopping sequences

$X_0(\cdot)$ = [	0	1	2	3	4	5	6	7	8	9	10	]
$X_1(\cdot)$ = [	0	2	4	6	8	10	1	3	5	7	9	]
$X_2(\cdot)$ = [	0	3	6	9	1	4	7	10	2	5	8	]
$X_3(\cdot)$ = [	0	4	8	1	5	9	2	6	10	3	7	]
$X_4(\cdot)$ = [	0	5	10	4	9	3	8	2	7	1	6	]
$X_5(\cdot)$ = [	0	6	1	7	2	8	3	9	4	10	5	]
$X_6(\cdot)$ = [	0	7	3	10	6	2	9	5	1	8	4	]
$X_7(\cdot)$ = [	0	8	5	2	10	7	4	1	9	6	3	]
$X_8(\cdot)$ = [	0	9	7	5	3	1	10	8	6	4	2	]
$X_9(\cdot)$ = [	0	10	9	8	7	6	5	4	3	2	1	]

.9.2Sequences $X_{ci}(\cdot)$ of length 11 (n_I = 11-ary), selected by c_i = (cell_id) mod 10.

Note: These sequences are generated according to construction 2 of ref. 12 using the Galois field GF(11). A useful formula is $X_n(\cdot) = (X_0(\cdot)\cdot(n+1)) \bmod 11$, for n = 1 to 9.

These sequences are read out at each increment of the frame number FN, where FN counts cyclically mod 77, according to the following rules:

i = (FN mod 11) → index $Xc_i(i)$
j = (FN mod 7) → sub band $Wc_o(j)$

These indices are used as follows to generate frequency sequences for downlink DL and uplinks UL_0 , UL_1, UL_2 and UL_3 for K=4.

$F_{cell\_id}DL(FN)$ = [sub band = $Wc_o(j)$, index = $Xc_i(i)$]
$f_{cell\_id}UL_0(FN)$ = [sub band = $(Wc_o(j)+3) \bmod 7$, index = $Xc_i(i)$]
$f_{cell\_id}UL_1(FN)$ = [sub band = $(Wc_o(j)+3) \bmod 7$, index = $(Xc_i(i)+3) \bmod 11$]

$f_{cell\_id}UL_2(FN)$ = [sub band = $(Wc_o(j)+3) \bmod 7$, index = $(Xc_i(i)+6) \bmod 11$]
$f_{cell\_id}UL_3(FN)$ = [sub band = $(Wc_o(j)+3) \bmod 7$, index = $(Xc_i(i)+9) \bmod 11$]

From the sub band and index there is a final mapping to the actual frequency, using

$f_{cell\_id}(FN)$ /MHz = 2403 + 11 * sub band + index.

The frequencies f are in the range $f \in$ [2403 MHz .. 2479 MHz]. (The sub band centre frequencies are 2408 MHz, 2419 MHz, 2430 MHz, .. 2474 MHz, and are not aligned to the centre frequencies of the channels in IEEE 802.11.)

Figure 9 shows an example of resulting hopping sequences over a cycle of 77 frames. Figure 10 shows the slot and frame timing relationships.

Note on implementation: Figure 8 shows the logical structure of the hopping sequence generation. The implementation may use different methods to store and generate the sequences W, X, and f.

.9.3Properties of hopping sequences $f_{cell\_id}(FN)$

- There are 60 different sequences fcell_id(FN). The sequences are periodic with a period of 77 frames.
- By construction, frequencies in consecutive frames are in different sub bands, i.e. spaced at least 11 MHz.
- The (duplex-) spacing between downlink and uplink frequencies is 3 sub-bands, i.e. at least 22 MHz.
- Concurrent uplinks are in the same sub band and spaced at least 2 MHz (mostly, 3MHz) for K=4.
- Hamming cross correlation properties affecting inter-cell interference are described in the Appendix A.

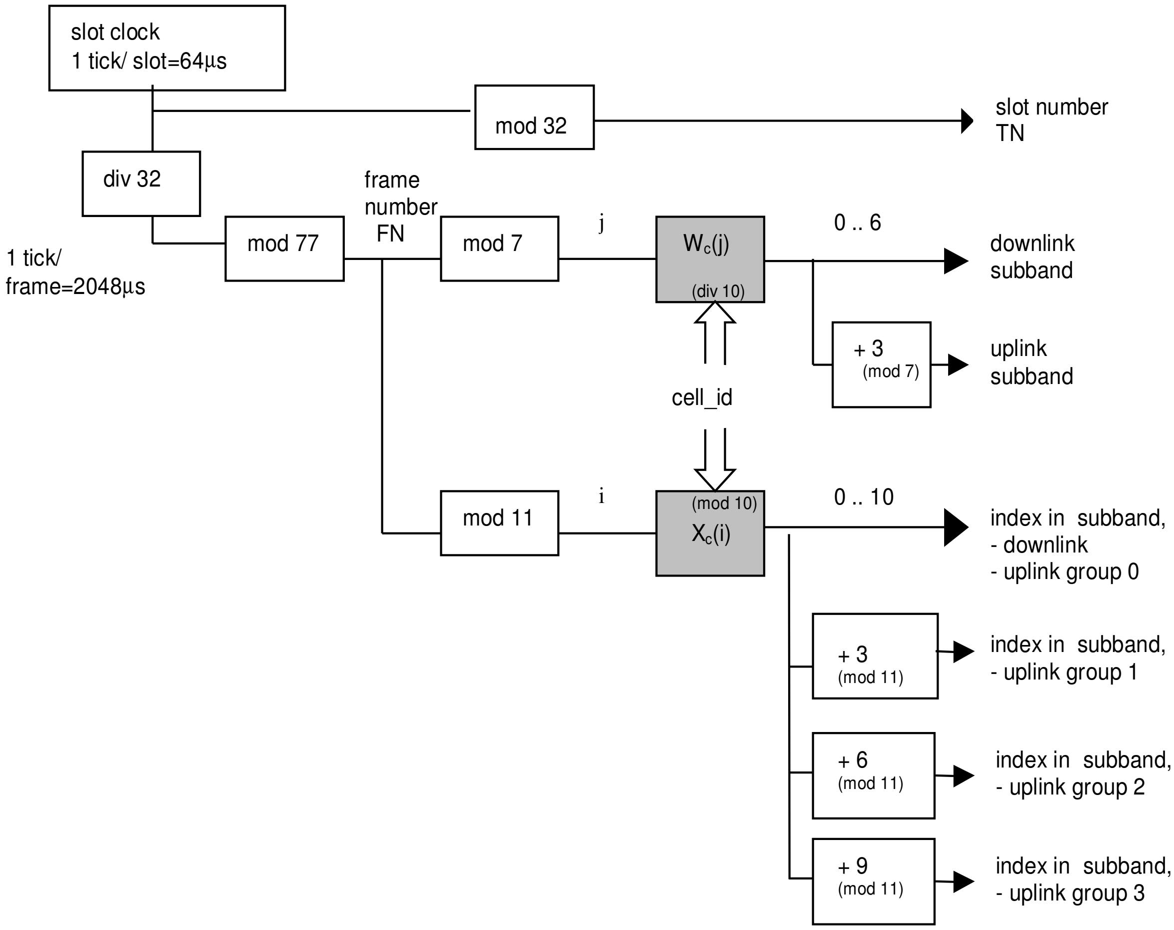

Figure 8: Hopping sequence generation, K=4

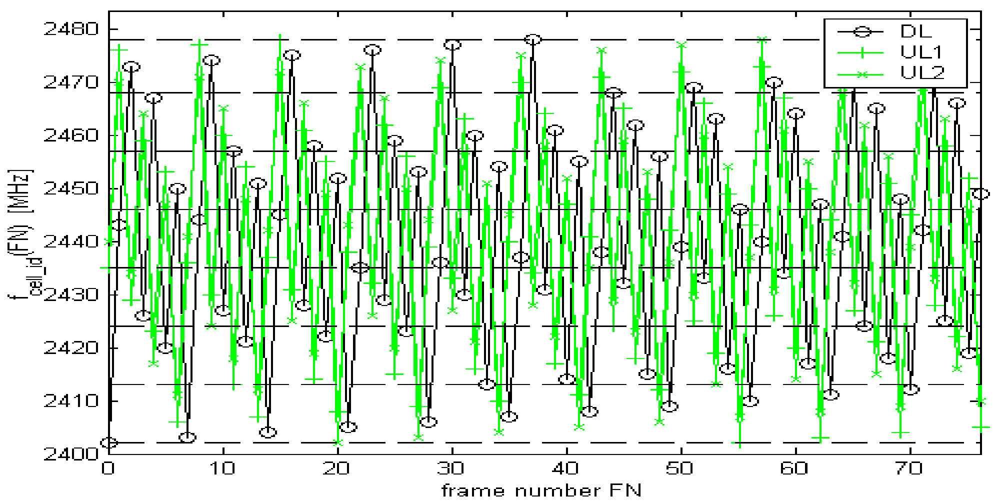

Figure 9: Hopping sequences, example with *cell_id* = 27 **(K=2)**

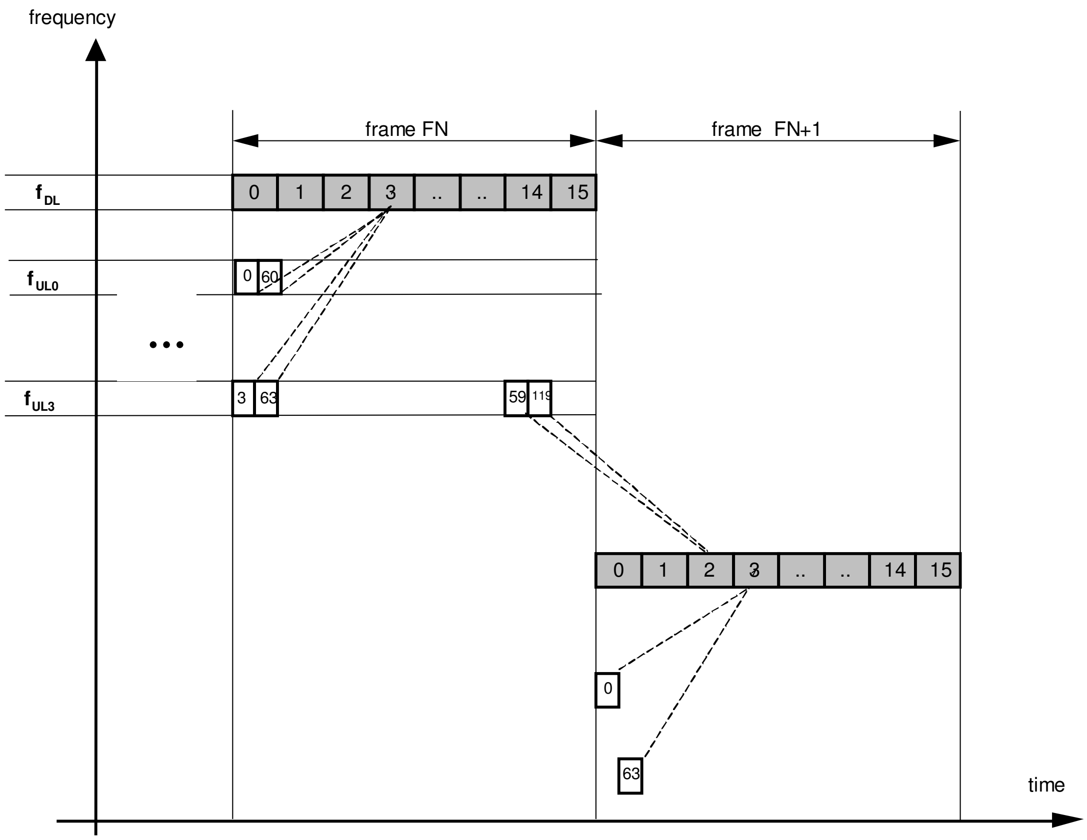

Figure 10: Illustration of the FH pattern, K=4. Shaded = downlink, white = uplink

With frame duration T_{frame} = 2048μs. K = 4 concurrent uplink frequencies. Dotted lines connect TX/RX slots of one sensor for a given frame, including TX/RX-turnaround time.

10System Configuration

The basic configuration of the SA like assigning the cell id and SA number is done on separate frequencies and under configuration mode operation. The configuration is performed using the configuration channels, which are separate physical channels. This configuration will synchronise the SA to the BS and allows further interactions.

If further configuration of the SA is required like downloading set points, this will be done under normal mode operation. This further configuration is performed using the control channel, which is multiplexed with the normal data channel using the general frequency-hopping scheme. Such download of parameters will be defined in the specific profiles.

Table 4: Configurable parameters

Parameter	Comments	Affects
Cell_id	The cell identity, 8 bits, cell_id ∈ [0 .. 59]	SA-BS
SA_no	Sensor/Actuator identity number, SA_no ∈ [0 .. 119]	SA-BS
Profile number	See 12.	
Version no.	System version number	SA-BS
FN	Frame Number, FN ∈ [0 .. 76]	SA-BS
Antenna switching	Antenna switching on/off if available	BS

The SA_no should be allocated so as to reduce the inter cell SA interference.

The Cell_id for individual cells must be unique. This is likely to have to be enforced by the operator of the total system.

The maximum number of SA's, using the maximum number of cell with unique frequency sequences, is 120 * 60 = 7200.

The version number is to allow for coexistence of different versions of the system. This is not an operator configurable parameter. The use of the version number will be defined when required.

.10.1Configuration Protocol

See ref. 12 for functional requirements. The Base Station shall mute its transmission until it has acquired at least a proper Cell_id.

.10.1.1Configuration of SA

The Base Station starts to transmit the configuration message when activated by the operator. The configuration message is transmitted continuously until acknowledged by the SA. The SA_no to be configured is the same as on the control panel. The SA shall read the configuration message after the operator has pressed the SA's foil-switch.

The Base Station transmits the configuration commands on 2402 and 2480 MHz alternating with **4** normal frequency hopping frames in-between each configuration command. The SA acknowledges the configuration command on the normal operating frequencies and in its allocated slot. The base station returns to normal frequency hopping after the acknowledgement.

The frame numbers used during configuration carries over into the operational mode, e.g. if FN = 14 at the last configuration frame, it will be 15 at the following frame under normal operation. Also if the configuration mode is entered from normal operation mode the frame number shall be continuous.

.10.1.1.1Configuration Frame

Configuration and replacement is common to all profiles / SA types. Therefore the configuration frame is described here rather than in the WISA Profile Specification 12.

Identical configuration messages are transmitted in the payload of all 15 double-slots of a configuration frame. Since the configuration frames are transmitted on separate frequencies, no special identification is required inside the message. In this case, the payload has the following meaning:

SA_no 8	Profile 8	Version 8	FN 8

Figure 11: Downlink configuration message

The correct Cell_ID is obtained from the message header.

The control bits of the downlink telegram shall be set to 0.

1) SA_no=255 is used as a broadcast delete command to any sensors that are not configured with the correct Cell ID. The Delete Configuration command must be received after the foil-switch has been pressed for more than 5 seconds before acted on by the SA.

.10.1.2Setting SA to Clean-Mode

The SA can be set to Clean-Mode (deleted) in a number of ways:

The delete can be initiated by an operator at the SA by pressing the foil-switch for at least **15** seconds. If the SA is able to communicate with the base station, the SA will send a delete request. Only if the base station is in the Delete Mode will it acknowledge the delete request and delete its own configuration information for that particular SA. On receiving the acknowledgement the SA will delete its configuration information and turn on its LED.

If the SA is unable to communicate with the base station, it will start to monitor the configuration frequencies. If any base station is in the Delete Mode it will send a Delete

[1] Delete broadcast has been removed from the system requirement for security reasons. The original description is retained here, but has never been implemented.

broadcast (not addressed to a particular SA) which will allow the SA to delete its configuration information.

It is be possible for the base station to retain connections with the operational SA while transmitting Delete broadcasts on the configuration frequencies. In this case the addressed and broadcast Delete can be handled concurrently. TBC.

The delete can be initiated by an operator at the base station by entering the SA number via the MMI. The base station starts to transmit the delete command in the relevant Dslot in all frames. The SA can read this message at any time but at the latest in conjunction with the next IMA message. The SA acknowledges the delete command and deletes its configuration information. The SA should turn on its LED to ease the identification of the SA for the operator. The base station deletes the SA configuration information on receiving the acknowledgement or after a **5** seconds timeout.

.10.1.3Replacement of SA

The replacement of a SA is identical to the configuration command as far as the air interface is concerned.

.10.1.4Usage of CCH

See document on installation, section 1.4, ref. 12:

The CCH shares the basic frame and slot formats with the data channel DCH. In the protocol, DCH slots may pre-empt (override) CCH slots. The DCH is distinguished from CCH slots by the extra bit (‘C bit’) in the uplink message header and is part of the message in the downlink.

The following configuration and control shall be possible (if applicable):

- BS sends configuration parameters to sensor/actuator
- BS requests serial-id
- BS requests sensor/actuator status & flashing
- Sensor/actuator responds with status
- BS requests test modes, e.g. loop-back of data

The SA shall be able to transfer messages of ca. 50 bits, possibly fragmented over several slots in both directions.

.10.1.5Usage of DCH

- Sensor/actuator sends data
- Sensor/actuator sends I’m Alive (IMA) signal
- Basestation sends actuator data

.10.1.6Error reporting

[2)] If an SA transmits consistently in a slot that it has not been configured for, this shall cause an error message to be sent to the PLC TBC.

11Profiles (empty)

The content of this section has been put into a separate document “WISA Profile Specification” 12.

[2] Not implemented

12References

[1] W.C.Y. Lee, "Mobile Communications Engineering," McGraw-Hill, 1982

[2] PBA 313 01/ 2 Bluetooth Radio, Ericsson product data sheet, October 2001.

[3] G.F.M. Beenker et. Al., "Binary Sequences with a Maximally Flat Amplitude Spectrum," Philips Journal of Research, Vol. 40, No. 5, 1985, pp. 289-304

[4] Specification of the Bluetooth System, Version 1.0 A, 26.7.1999

[5] G.C.Clark, Jr., J.B.Cain, "Error-Correction Coding for Digital Communications," Plenum Press, 1981

[6] Stefan Ramseier (Ed.), Wireless Proximity Sensor, Prototype Design Specification – Communications Subsystem. 538203030ProxiProtDesignCommsRev1.doc, 2000-7-12

[7] A.A.Shaar and P.A.Davies, "A survey of one-coincidence sequences for frequency-hopped spread spectrum systems," IEE Proceedings, Vol.131, Pt.F, No.7, December 1984, pp.719-726.

[8] Christoffer Apneseth, Dacfey Dzung, Jan Endresen, "WPS Communication Threats and Evaluation of Solutions," ABB Corporate Research, November 2001.

[9] Installation Documentation

[10] WPS Requirement Specification.
File APH-WPS-020225.doc, 7 June 2002.

[11] EN 300.328 latest version.

[12] FCC 15.247 latest version.

[13] Endresen, Vallestad: „WISA Profile Specification"; latest version.

13Revision history

1.0	First official release	2002-02-28
1.1	Document updated in response to issues raised during design and specification. UL and DL change frequency at the same time. Only BS uses the configuration channels. Wink command from sensor. More explicit use of acknowledgements. General delete mode included.	2002-05-28
1.2	Document updated after review 2002-06-06 A maximum of 120 sensors/actuators have been put in section 6.1 and with some simplifications in section 10.1. Section 10.1.2 (delete) has been updated according to ref. 12. All commands are now acknowledged (they count as IMA's). A sensor command "Senor restarted" a been added to allow the sensor to notify the BS of a restart.	2002-06-12
1.3	Scrambling of the uplink and downlink has been included, see sections 7 and 8. Four possible parallel uplinks have included to accommodate 120 sensors per base station, see sections 6.1 and 9.1 New profile for 120 sensors has been added, see section 11.	2002-09-15
1.4	Ambiguity removed from Table 5.	2002-09-25
1.5	Section 10.1, 10.1.1, 10.1.2, 11.2.3 and tables 4, 7, 9 and 12 have been updated to reflect "as built"	2003-04-20
1.6	Redefinition of Cell ID in uplink message (Figure 6) to protect against cross-talk. New base station command defined to be able to read sensor version number (Table 6 and Table 7). Minor modification to Table 6 and Table 7. The sensors shall transmit the initial IMA's in certain frames.	2003-10-09
1.7	New command in Table 6 and added Table 9.	2003-10-20
1.8	60 Sensor (K=2) removed and added profile for 16-bit I/O 11.4	2004-06-11
1.9	Added new bullet for uplink Dslot to section 6. Added last paragraph about possible cross talk between uplink Dslot and uplink single slot to section 6. Added Figure 7 for uplink Dslot. Added section 11.4.	2005-02-16

1.10	Additions and changes are in blue. Removed the ‘WRIO’ profile (Profile 4). Renamed figures and tables to get unique names. Added test and tables/figures in sections 6.1 and 11.5. Corrected section 6, paragraph 10: 5 frequencies (not 3). Corrected Figure 7: Product code encoded uplink Dslot message (‘long’ telegram): K8 byte shall appear twice. Corrected Table 10: transmit data info to the BS (not SA).	2005-06-27 (never got past the ‘draft’ stage)

1.11	Additions and changes are in red. Removed the content of section 11 (Profiles), including Tables 5 to 17. And Figures 11 to 17. Put most of it into a separate document (Wisa Profile Specification). Section 11 is still present here, now only with a reference to the new document. Sub-sections 11.2.3 'Sensor configuration and replacement' and 11.5.4 'I/O node configuration and replacement' were however combined – they were essentially equal – and moved to section 10. References to the old section 11 were replaced with references to the new document. Re-wrote sections 1 and 2 to reflect the split to two documents. Section 6: Changed UL group numbering from 1..4 to 0..3. Changed the number 2 to 3 in the sentence "A sensor/actuator transmitting in a certain uplink slot assigned to it, must read the downlink Dslot delayed by **3** Dslots for the BS acknowledgement". Section 9: Updated figures 8 and 10 (but not figure 9) to reflect K=4. Changed UL group numbering from 1..4 to 0..3. Changed "at least 3 MHz" to "at least 2 MHz (mostly, 3 MHz)" in section 9.3. Section 10.1.1: Changed the number 3 to 4 in the sentence "The Base Station transmits the configuration commands on 2402 and 2480 MHz alternating with **4** normal frequency hopping frames in-between each configuration command". Added section 10.1.1.1 (see above). Added footnote informing that Delete Broadcast is not implemented. Section 10.1.2: Changed the number 5 to 15 in the sentence "The delete can be initiated by an operator at the SA by pressing the foil-switch for at least **15** seconds". Section 10.1.6: Added footnote informing that "If an SA transmits consistently in a slot that it has not been configured for, this shall cause an error message to be sent to the PLC" has not been implemented. The figures earlier numbered 18 to 21 (in the appendices; sections 14, 15 and 16) are now numbered Figure 11 to Figure 14.	2005-09-20

14 Appendix A: Cross-correlation properties of FH sequences

The potential inter-cell interference is determined by the Hamming cross-correlation of the 2 sequences $f_{cell\_id}(FN)$ pertaining to 2 different cell_ids. The cyclic Hamming cross-correlation of multilevel sequences f(FN) is defined in ref. 12. Ref. 12 also describes construction methods for one-coincident sequences W(·) or X(·). Here we verify the cross-correlation of the combined sequences $f_{cell\_id}(FN)$ = [sub band $W_{co}(j)$, index $X_{ci}(i)$].

For the wanted cell with cell_id = 27, Figure 12 and Figure 13 show the maximum cross-correlation over all relative phases due to the FH sequences from all other cells with cell_id between 0 and 59. Apart from the own cell, the maximum correlation is 11 hits in a period of 77 frames. Detailed analysis reveals that these hits are spaced regularly 7 frames apart. The SA ARQ scheme using a window of 7 frames should be able to recover from such hits.

Figure 13 shows that there is a maximum correlation of 77/77 for the 3 sequences of a given cell_id. However, this occurs for a relative phase ≠0, which will not occur in practice since the sequences of a given cell are by definition synchronous with phase 0.

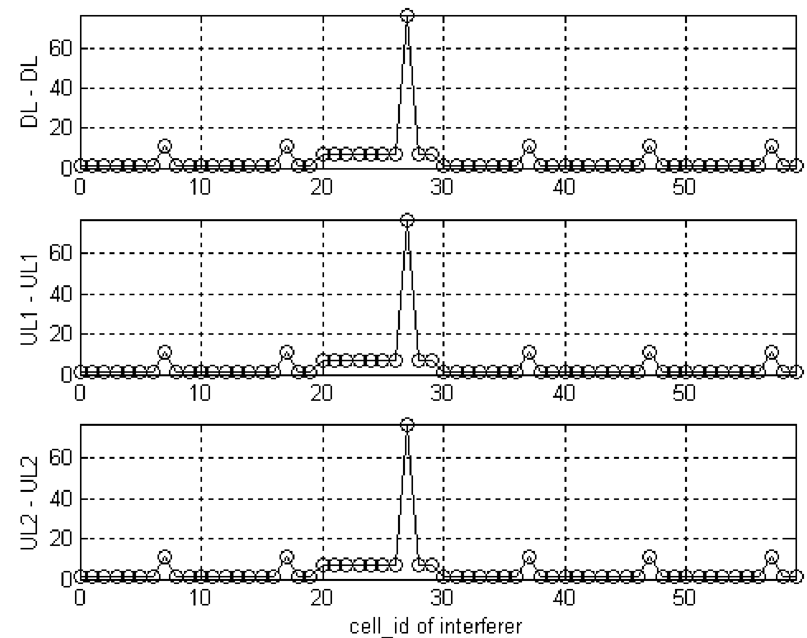

Figure 12: Maximum Hamming cross-correlation – same direction

top:	wanted downlink cell_id=27, interference from other downlink
centre:	wanted uplink 1 cell_id=27, interference from other uplink 1
bottom:	wanted uplink 2 cell_id=27, interference from other uplink 2

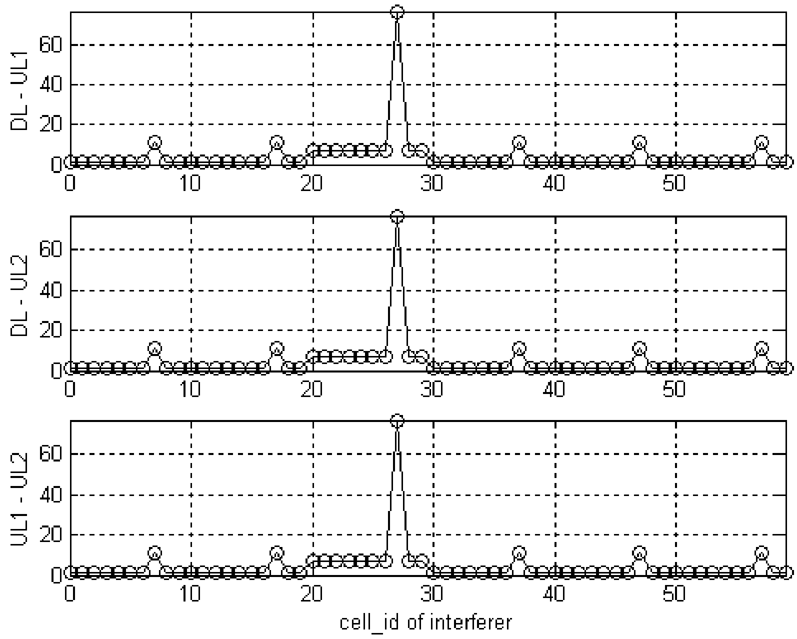

Figure 13: Maximum Hamming cross-correlation – different direction

top: wanted downlink cell_id=27, interference from other uplink 1
centre: wanted downlink cell_id=27, interference from other uplink 2
bottom: wanted uplink 1 cell_id=27, interference from other uplink 2

(Figure 13 looks the same as Figure 12: For any given cell_id, there are non-zero phases $\tau 1$, $\tau 2$, for which $f_{cell\_id}^{DL}(FN) = f_{cell\_id}^{UL1}(FN+\tau 1) = f_{cell\_id}^{UL2}(FN+\tau 2)$. Hence maximum cross-correlations become identical.)

15Appendix C: Message Sequence Charts

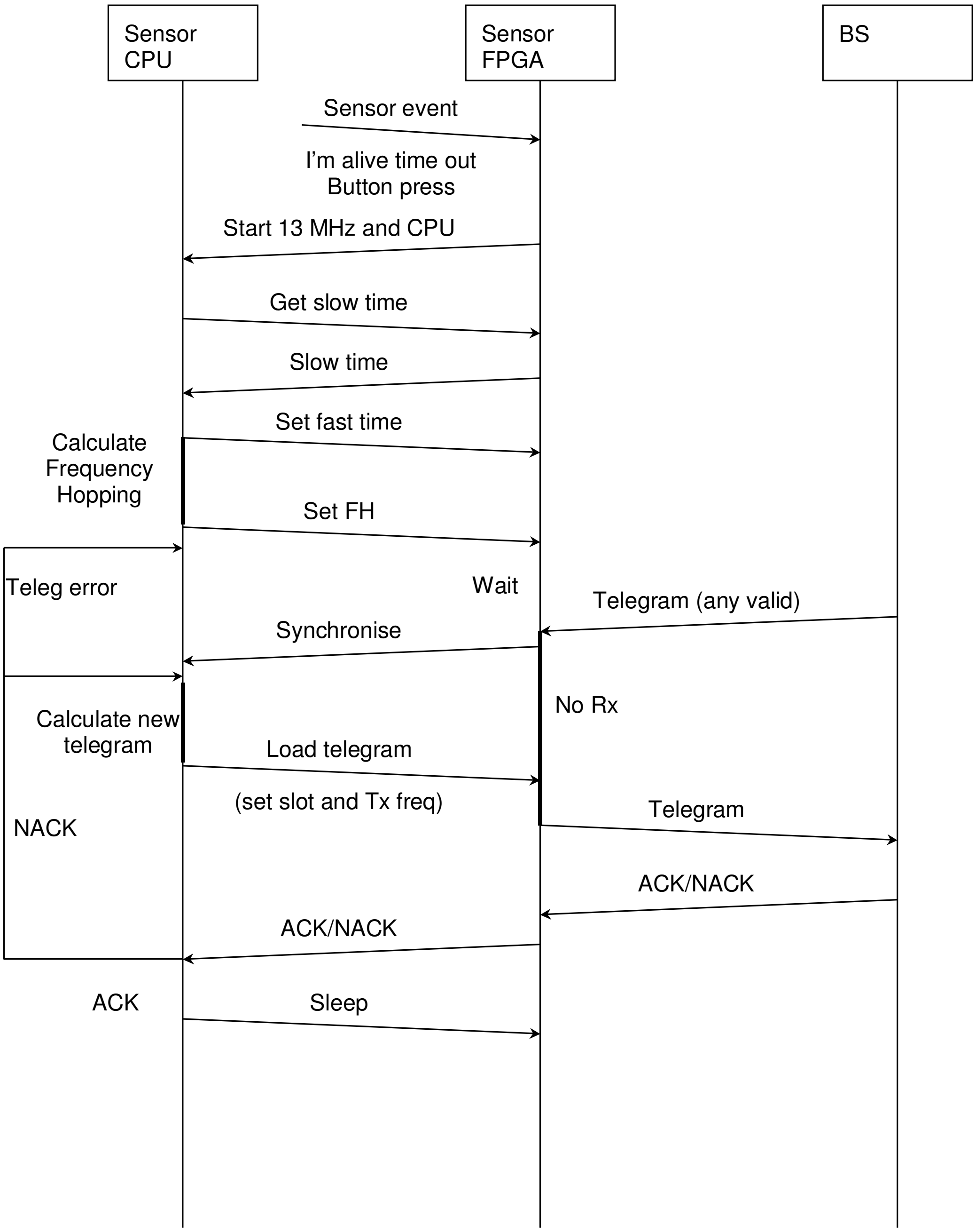

Figure 14: Normal Message Sequence Chart for a sensor

16Appendix D: CRC Performance

Figure 15 shows the probability of undetected errors for the repeated code as a function of the Bit Error Rate on the radio link.

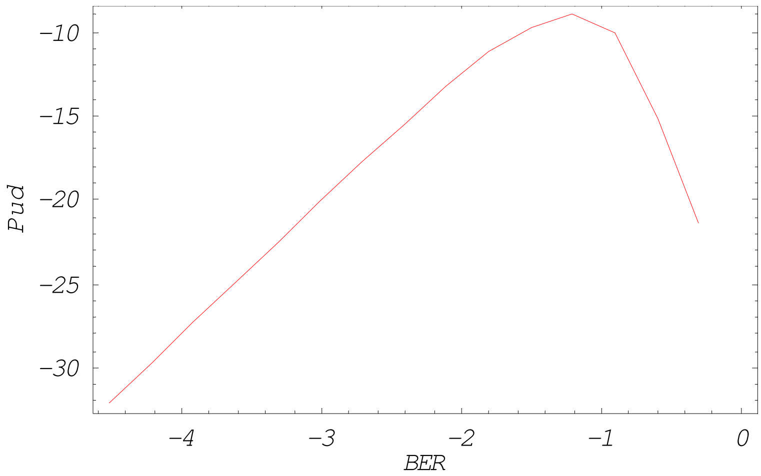

Figure 15: Probability of undetected error for repeated code vs. BER (log-log)