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Planning Smart Cities using Wireless Low Energy Monitoring Systems

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Abstract

Modern cities and large utility companies need to implement new or expanding measurement strategies and technologies to exchange information with each client, in real time. This will allow better control over the grid network and reduce operating costs while maintaining the grids in a higher realm, fighting against fraudulent customers. Some of these systems are based on the IEEE 802.15.4k variant, where information is transmitted in wireless mode around of 169MHz, using very low power devices which can increase battery lifetime by several years.

Telemetry systems are designed to automatically collect meter consumption data, transfer and stored them in a central database, internal or external to the management company for billing purposes or others. Implementation of such systems allow more reliable and frequent readings, eliminating the usual rough estimates of consumption, often exaggerated by allowing more efficient charging and a reduction in the number of customer complaints. The information obtained can also be used for technical purposes, such as park management accountants, network planning and design of expansion and maintenance of the network (audits excesses in consumption and control of real excesses by customers).

This thesis is focused on the study of telemetry systems using low consumption equipment (operating in the frequency region of 169MHz), and network planning of such systems in different scenarios, as well as practical implementation of a typical scenario in order to verify the analysis results and benefits.

Specifically, the study of these systems goes through deepening their definitions and characteristics to be able to plan possible network telemetry. After the theory part, a possible scenario will be considered for practical implementation of these systems. The solution is to installing a device in a counter and after certain times, for example each hour, send for a Gateway, where it will arrive to the regulatory authority.

Keywords

WM-Bus, Planning, Coverage, Telemetry Counters, Capacity

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List of Acronyms

ACC	Access number
ACC_DMD	Access Demand
ACC_NR	Access-No Reply
ACD	Access Demand
ACK	Acknowledgment
AES	Advanced Encryption Standard
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
CBC	Cipher Block Chaining
CNF_IR	Confirm Installation Request
CRC	Cyclic Redundancy Check
DAL	Dedicated Application Layer
DES	Data Encryption Standard
DFC	Data Flow Control
EIRP	Equivalent Isotropically Radiated
ETSI	European Telecommunication Standardization Institute
FCB	Frame Count Bit
FCV	Frame Count Bit Valid
FDM	Frequency Division Multiplexing
FSK	Frequency Shift Keying
GFSK	Gaussian Frequency Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HHU	Hand-held Units

ISM	Industrial, Science and Medical
ISO	International Organization for Standardization
LBT	Listen-Before-Talk
LOS	Line-of-Sight
PL	Path Loss
NRZ	Non-Return-to-Zero
OSI	Open Systems Interconnection
PER	Packet Error Rate
PRM	Primary Message
REQ_UD/REQ_UD2	Request User Data
RES	Reserved
RF	Radio Frequency
RSP_UD	Respond User Data
RSSI	Received Signal Strength Indicator
RX	Receive
SND_IR	Send Installation Request
SND_NKE	Send Link Reset
SND_NR	Send-No Reply
SND_UD/SND_UD2	Send User Data
SRD	Short Range Devices
TX	Transmit
VHF	Very High Frequency
WM-BUS	Wireless Meter Bus
WSN	Wireless Sensor Network

List of Symbols

A	Attenuation Parameter
BPL	Building Penetration Loss
d	Distance Between Transmitter and Receiver
dB	Decibel
f	Frequency
h_c	Collector Antenna Height
h_e	Endpoint Antenna Height
Hmu	Correction Factor of the Endpoint Antenna Height
Lp	Propagation Loss
Msens	Meter Sensitivity
R	Cell Radius
RF Margin	Rayleigh Fading Margin
Sdesign	Required Sensitivity.
Ttx	Period of Transmission
σ_{LNF}	Log-Normal Fading
K_{hp}	Position the Handset in the Rolling Terrain
K_{th}	Rolling Terrain Correction
K_{sp}	Slope Terrain Correction
K_{mp}	Mixed Path Correction
K_{al}	Along Path Correction
K_{ac}	Across Path Correction
$K_{su}(f)$	Suburban Correction
K_{oa}	Open Areas Correction
K_{qo}	Nearly Open Correction

Chapter 1

Introduction

This chapter gives a brief overview of the work. Before establishing targets and original contributions, the scope and motivations are brought up. The current State-of-the-Art concerning the scope of the work is also presented. At the end of the chapter, the work structure is provided.

1.1 Overview

Nowadays wireless sensor networks (WSN) are becoming a technology capable of operating in many different systems and environments from wide geographical area to small-scale areas. WSNs are currently deployed in several applications, such as the buildings construction, traffic monitoring, environmental analysis, health, weather, and many others. These networks can enhance the way that people interact with the surrounding environment, to increase their life quality and reduce the waste of natural resources (water, oil and gas), while optimizing their use. A relevant task from this perspective is represented by fine measurements, that is, the ability to measure the amount of particular resources available at a specific point several times per day.

This work is devoted to domestic telemetry systems. The thesis general objective is to get a better understanding of monitoring systems, protocol specifications and wireless coverage in different scenarios in order to achieve a low cost network.

In this context, household telemetry systems are developed in the 169MHz band, propose changes in the reading traditional model, where basically services suppliers can estimate energy consumption, starting to have a model more real and frequent reading. Not only there will be an evolution in terms of business from suppliers, but also improves control over network resources and reduce operational costs.

In order to achieve the general objective of this work is necessary to deeply know the protocol specifications in order to be able to study a realistic network scenario. Communication technology is based on IEEE 802.15.4 ZigBee, widely used in networks with low power sensors, and the WM-Bus a recent protocol proposed by the Group Open Metering System [1] for measurement scenarios. It is described by the European standard (EN 13757-2 physical layer and link, application layer EN 13757-3) for remote reading of gas meters, water, electricity and also for other types of consumption meters.

The Wireless M-Bus standard [2] [3] specifies the RF communication link between water, gas, heat, and electric meters and the data collecting devices and is becoming widely accepted in Europe for smart metering or Advanced Metering Infrastructure (AMI) applications (Figure 1). Wireless M-Bus (WM-Bus) was originally targeted to operate only in the 868MHz band, which gives a good trade-off between RF range and antenna size. Recently two new bands (169MHz and 433MHz) have been added to the WM-Bus specification as well, introducing narrow-band solutions with much better link budget and thus providing longer range solutions than at 868MHz.

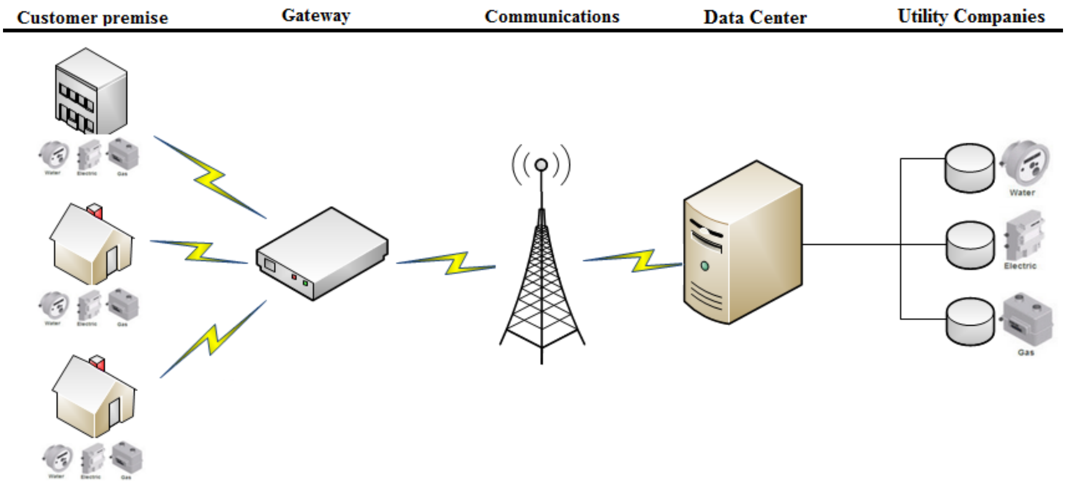

Figure 1 – Advanced Metering Infrastructure System.

The network between the measurement devices and business systems allows collection and distribution of data and information to customers, suppliers, utility companies, and service providers. This enables these businesses to participate in demand response services. Consumers can use information provided by the system to change their normal consumption patterns and thus take advantage of lower prices.

AMI systems differ from traditional automatic meter reading (AMR) as they enable two-way communications with the meter. Systems only capable of meter readings do not qualify as AMI systems.

1.2 Motivation and Contents

In recent times, the telecommunications world has witnessed a great development with regard to the introduction of new technologies and new services.

The cost reduction for the wireless technology has increased the number of applications, where the remote monitoring and metering are included. This has caused many companies to dedicate their research to the development of wireless sensor platforms, known as Smart Meters, aimed at this purpose.

The Smart Meters are defined as advanced energy, water, or gas meters which measure the energy consumption of a consumer and provide added information to the energy provider companies. Smart meters can read real-time energy consumption information and securely transmit data.

The network platform we are proposing is based on the 169MHz frequency band. This band designated WM-BUS is a new European standard reserved for the remote reading of various meters of domestic consumption and other types of meters and sensors. This standard provides gains a great importance to the energy industry, for customers and suppliers.

The remote meter reading can occur in different ways, the classic method consisting in manual reading by the supplier's personnel or remotely controlled reading of all the counter values for a complete housing. The latter one is a logical continuation / extension of the technical development of consumption meters and is achievable with the help of M-Bus.

This work is organized into five chapters.

- Chapter I – Consists of the introduction, state of the art, motivation and a brief description of the thesis structure;
- Chapter II – Highlights the main features of WM-Bus standard;
- Chapter III – The processes involved in the planning of coverage and capacity of WM-Bus network;
- Chapter IV – In this chapter, it performed a simulation and results analysis on the evaluation of standard WM-Bus.

1.2.1 Planning of project activities

Further analysis should be done in relation to existing devices on the market. In particular the analysis on Power consumption and costs.

Chapter 2

Wireless M-Bus

The second section is dedicated to the meter bus standard. Initially, the section gives a short overview of the origin of the WM-Bus protocol stack and the standard series structure. The following sections discuss the relevant technical details.

2.1 M-Bus Standard

2.1.1 History of M-Bus

The M-Bus communication standard has its roots in the water, energy and gas metering industries. Prof. Dr. Horst Ziegler, while holding a chair at the physics faculty at the University of Paderborn in Germany, is accredited with the initial concepts of remote meter reading as defined in the M-Bus and OMS standards today.

In the meantime the M-Bus has become the preferred bus system among several meter vendors and utilities across Europe. According to an Open Meter workshop note, 15 million devices were relying on the wireless version of M-Bus in 2010.

2.1.2 Standard Overview

The Metering Bus (or in short "M-Bus") is a field bus specialized for transmission of metering data from gas, electricity, heat, water or other meters to a data collector. It is described by European Norm (EN 13757), which includes the specification of wired and Wireless M-Bus. The specification is divided into six parts.

- EN 13757-1 [4] Communication systems for meters and remote reading of meters - Part 1: Data Exchange.

The first part describes the basic communication between the meters and a central data collector. It provides an overview of the communication system. It further gives an introduction into the protocol stack and the metering architecture which is proposed to be a tree structure. The standard makes use of the term "collector" for devices which serve as an upstream device or as a master node for several other meters.

- EN 13757-2 [5] Communication systems for meters and remote reading of meters - Part 2: Physical and link layer.

The second part includes the specification of the physical data transmission using wired connections. It also includes the description of the protocol to transmit the data. This part specifies the master-slave concept and foresees an address space of 250 addresses for unique addressing of slave devices. The standard further specifies the binary representation of the current loop (twisted pair, baseband) in the form of electrical signals in voltage and current levels.

- EN 13757-3 [6] Communication systems for meters and remote reading of meters - Part 3: Dedicated application layer (DAL).

The third part describes a standardized application protocol to enable multivendor capability. So devices of different manufacturers may be combined in one system.

- EN 13757-4 [2] Communication systems for meters and remote reading of meters - Part 4: Wireless meter readout (Radio meter reading for operation in the 868MHz to 870MHz short range device (SRD) band)

This part specifies the wireless communication of M-Bus and is the main source document for this implementation. It includes the Physical and the Data Link Layer for wireless devices. It corresponds to specification EN 13757-2 for wired communication. As the title implies this part specifies the frequency spectrum, bands and communication types for wireless meter readout.

- EN 13757-5 [7] Communication systems for meters and remote reading of meters - Part 5: Wireless relaying

This part includes different proposals for relaying data frames to overcome the range problem between remote meters and data collectors.

- EN 13757-6 [8] Communication system for meters and remote reading of meters - Part 6: Local Bus

This part specifies an alternative to the M-Bus and is designed as a 3 wire serial line. The local bus allows for local readout with battery powered Hand-held Units (HHU) or mini-master whereby the meter must be self-powered. Using the local bus, a minibus of up to 5 devices could be read.

2.2 Wireless M-Bus Introduction

This section briefly introduces M-Bus communication based on the WM-Bus stack and its related transmission modes as defined in current and draft standards.

Short or medium range communication technologies must ensure minimal power consumption. The ZigBee or other solutions based on IEEE802.15.4 have been widely used in networks with low power sensors, such as the WM-Bus protocol have been recently proposed by the Open Metering Systems Group for metering scenarios. The WM-Bus devices require low power consumption thanks to a low-overhead protocol, transmission-only modes (which do not require an idle receive phase), and long range sub-GHz transmission bands. While the first document EN 13757-4:2005 prescribed the use of the 868MHz Industrial, Science and Medical (ISM) and 468MHz bands, the later version EN 13757-4:2011 added new transmission modes at 169MHz bands, with lower data rate . The lower 169MHz frequency band enables longer transmission range due to the inherently lower path losses, while the reduced data rates enable higher sensitivity for the receiver, allowing a reduction of the transmission power at the transmitter, or a longer transmission range, at parity of the transmission power.

Based on the specific application, there are combinations of communication modes for data collectors and metering devices. These settings define the communication flow and the configuration of the radio channel. In Subsection 2.2.2 lists the available communication modes.

The M-Bus is a specialized standard for data transmission over the counters of measures such as water meters, energy, gas and heat. It is described by the European standard (EN 13757-2 [5] physical and link layer, EN 13757-3 [6] application layer) for the remote reading of gas or electricity meters. M-Bus is also usable for other types of consumption meters. The M-Bus interface is made for communications on two wires, making it very cost effective. A radio variant of WM-Bus (Wireless M-Bus) is also specified in EN 13757-4 [2].

2.2.1 Protocol Stack

The OSI reference model provides a basis for the development of standards for Open Systems Interconnection (OSI). This model devised by the "International Organization for Standardization" (ISO) is intended to ensure that information from multiple systems manufacturers, with a different architecture, could be exchanged and construed in accordance with standard procedures.

This model organizes the communication functions into seven layers, each of which has a virtual connection to the appropriate layer of the communication partner. Only in the lowest layer (layer 1) there is a physical connection for exchanging signals.

The WM-Bus protocol stack is compatible to the international ISO/OSI-model, but only the layers 1, 2 and 7 are implemented.

Table 1 – Layers of OSI Model (adapted from [9]).

<table>
<tr><th colspan="3">OSI Model</th></tr>
<tr><th colspan="2">Layer</th><th>Data unit</th></tr>
<tr><td rowspan="4">Host layers</td><td>7. Application</td><td rowspan="3">Data</td></tr>
<tr><td>6. Presentation</td></tr>
<tr><td>5. Session</td></tr>
<tr><td>4. Transport</td><td>Segments</td></tr>
<tr><td rowspan="3">Media layers</td><td>3. Network</td><td>Packet/Datagram</td></tr>
<tr><td>2. Data link</td><td>Bit/Frame</td></tr>
<tr><td>1. Physical</td><td>Bit</td></tr>
</table>

The functions of the individual layers shown in Table 1 will now be explained in more detail:

Physical Layer

The basic physical connection between the communicating partners takes place in this lowest layer. The mechanical and electrical coupling to the transmission medium is determined here, by specifying (among other things) the cable, the distances involved, the pinning of connectors, and the way the bits are represented.

Data Link Layer

This layer is responsible for assuring that a reliably operating connection is made between two participants. For this purpose the protocol of this layer determines the methods for protecting transmissions, the telegram structure, methods of accessing the transmission medium and for the synchronization and addressing of participants.

Network Layer

The network layer undertakes the choice and implementation of the best transmission route in a network between the communicating parties, and provides this service (Routing) to the Transport Layer. This function is of particular significance when different networks need to be connected by means of Gateways.

Transport Layer

The transport layer represents the boundary between the application oriented layers 5 to 7, and the transport oriented layers 1 to 4. Its job includes guiding the information through the network, controlling the flow of information and the grouping into individual packets.

Session Layer

The session layer provides procedures for the opening, the orderly progressing, and the termination of a communication "session". In this is included also the control of the dialogue between systems: that is, the determination of their respective transmission prerogatives.

Presentation Layer

The data of the application are converted in the presentation layer into a data format which the receiving application can interpret. This layer thus implements the matching of data formats and the conversion of codes.

Application Layer

This top layer represents the interface between the open system and the user. It offers the user or his program a service allowing him to work easily with the system. Application programs which need to be developed can thus access the functions of the open system via the protocol of the application layer.

- **The M-Bus in the OSI Model**

The Meter-Bus (M-Bus) was developed by Professor Dr. Horst Ziegler from Paderborn University in cooperation with Texas Instruments Deutschland GmbH and Techem GmbH [10].

The concept was based on the ISO-OSI Reference Model, in order to realize an open system which could utilize almost any desired protocol.

Since the M-Bus is not a network, and therefore does not - among other things - need a transport or session layer, the levels four to six of the OSI model are empty. Therefore only the physical, the data link, the network and the application layer are provided with functions.

The protocol stack shown in Table 2 further describes a network layer which only exists with devices that support the M-Bus wireless relaying router approach. According to the specification a device depending on that protocol stack can communicate with its peers via a multitude of transmission modes.

Table 2 – WM-Bus Protocol Stack mapped to ISO/OSI Layers (adapted from [11]).

ISO/OSI Layer	Standard	Description
Application	EN 13757-3	M- Bus Dedicated Application Layer
Network	EN 13757-5	Wireless relaying (optional for meters supporting the router approach)
Data Link	EN 13757-2 or EN 13757-4	Physical and link layer or Wireless meter readout (Radio meter reading for operation in SRD bands)
Physical	EN 13757-2 or EN 13757-4	Physical and link layer or Wireless meter readout (Radio meter reading for operation in SRD bands)

Up to now, the application layer implements all other protocol layers required for a specific apliance. Especially if routing is required according to EN 13757-5, it is implemented in the application layer.

The reduced modularity leads to compact implementations running on very small devices with minimum computing resources. But the lack of modularity certainly is one of the reasons why standardized routing protocols are currently not available for Wireless M-Bus [12].

2.2.2 Communication Modes

Depending on the application there are various combinations of communication modes for data collectors and metering devices. These settings define the communication flow and the configuration of the radio channel.

The wireless meter readout draft standard physical layer defines six main modes in order to allow for optimization in power consumption supporting different use cases. Additionally, the wireless relaying standard specifies modes for routing and time synchronization between devices.

- **Stationary Mode** (S-868MHz, 32.7 kbps data rate) is to be used for communication with battery driven. Specific modes exist for one-way (S1) and two-way (S2) communication. In mode S2 the transmitter requires an acknowledge (ACK), differently from S1.

- **Frequent Transmit Mode** (T-868MHz, 100 kbps data rate from meter to gateway) is optimized for drive-by readout. As with mode S, mode T does provide specific modes for one-way (T1) and two-way (T2) communication. In mode T2 the transmitter requires an (ACK), differently from T1.
- **Frequent Receive Mode** (R-868MHz) allows for simultaneous readout of multiple meters. Where by only sub mode R2 is specified. The R2 sub mode is used mainly used for gateways and drive-by meter reading.
- **Compact Mode** (C-868MHz) is comparable to mode T but allows for increased data throughput. This is achieved by using NRZ for line coding which is more efficient than the Manchester code.
- **Frequent Receive and Transmit Mode** (F-433MHz) is optimized for long range communication and is also split into one-way and two-way sub modes.
- **Narrowband VHF Mode** (N-169MHz) is optimized for transmission within a lower frequency narrow band. It is intended for long range repeater use and does specify modes for one-way (N1a-f), two-way (N2a-f) and relay communication. the standard also foresees the following modes:

  Na mode: 169.40MHz, 4.8 kbps data rate. N2a requires ACK, N1a does not.

  Nc mode: 169.431MHz, 2.4 kbps data rate. N2c requires ACK, N1c does not.

  Ng mode: 169.437MHz, 38.4 kps data rate. Always requires ACK.

  and submodes:

  N1a-f: one-way transmission; the node transmits on a regular basis to a stationary receiving point; single hop repeaters are allowed;

  N2a-f: two-way transmission; the node transmits like N1a-f; its receiver is enabled for a short period after the end of each transmission and locks on if a proper preamble and synchronization word is detected.

In general, Wireless M-Bus modes can have different data rates, data encodings (e.g. Non-Return-to-Zero (NRZ) or Manchester), frequency modulations (e.g. Frequency Shift Keying (FSK) or Gaussian Frequency Shift Keying (GFSK)) and carrier frequencies. Table 3 lists the related parameters with respect to the Wireless M-Bus mode, the device type and whether a device is in Receive (RX) or Transmit (TX) mode.

Table 3 – Wireless M-Bus mode parameter settings (adapted from [13]).

Mode	**Meter**		**Collector**		**Data Rate**	**Encoding**	**Modulation**	**Frequency [MHz]**
	RX	TX	RX	TX				
N1a, N2a	x	x	x	x	4.8 kbit/s	NRZ	GFSK	169.406250
N1b, N2b	x	x	x	x	4.8 kbit/s	NRZ	GFSK	169.418750
N1c, N2c	x	x	x	x	2.4 kbit/s	NRZ	GFSK	169.431250
N1d, N2d	x	x	x	x	2.4 kbit/s	NRZ	GFSK	169.443750
N1e, N2e	x	x	x	x	4.8 kbit/s	NRZ	GFSK	169.456250
N1f, N2f	x	x	x	x	4.8 kbit/s	NRZ	GFSK	169.468750
N2g	x	x	x	x	38.4 kbit/s	NRZ	4 GFSK	169.437500
T2	x			x	32.768 kchip/s	Manchester	FSK	868.30
T1, T2		x	x		100 kchip/s	3-out-of-6	FSK	868.95
S1, S2	x	x	x	x	32.768 kchip/s	Manchester	FSK	868.30
C2	x			x	100 kchip/s	NRZ	GFSK	869.525
C2				x	32.768 kchip/s	Manchester	FSK	868.30
C2			x		100 kchip/s	3-out-of-6	FSK	869.95
C1, C2		x	x		100 kchip/s	NRZ	GFSK	868.95

Table 4, specifies the compatibility of different Wireless M-Bus modes.

Table 4 – Compatibility matrix for Wireless M-Bus modes (adapted from [13]).

	Meter S	**Meter T**	**Meter C**	**Meter N (a – f)**
Collector S	x			
Collector T		x		
Collector C		x	x	
Collector N (a – f)				x

In summary, the Wireless M-Bus modes S and N (in mode N, every sub-mode a − f is only compatible with the same sub-mode) are only compatible with the same Wireless M-Bus mode. But mode T is partially compatible to C - a data collector in mode C is able to communicate with a meter device in mode T.

- **Unidirectional vs. Bidirectional Communication**

If unidirectional communication is used, data will be sent from the metering device to the data collector only. This enables simple transmitters as metering devices while the data collector only needs to receive. Because listen-before talk (LBT) and dynamic network configuration are not possible, it is recommended to use the unidirectional modes for small and simple constellations with low network load.

In case of bidirectional communication, the collector device can request data from the meter device. This is for example the case in S2, T2, C2 and N2 mode. In these modes, a bidirectional communication will only be established if further data or commands need to be exchanged. Figure 2 shows a typical communication flow.

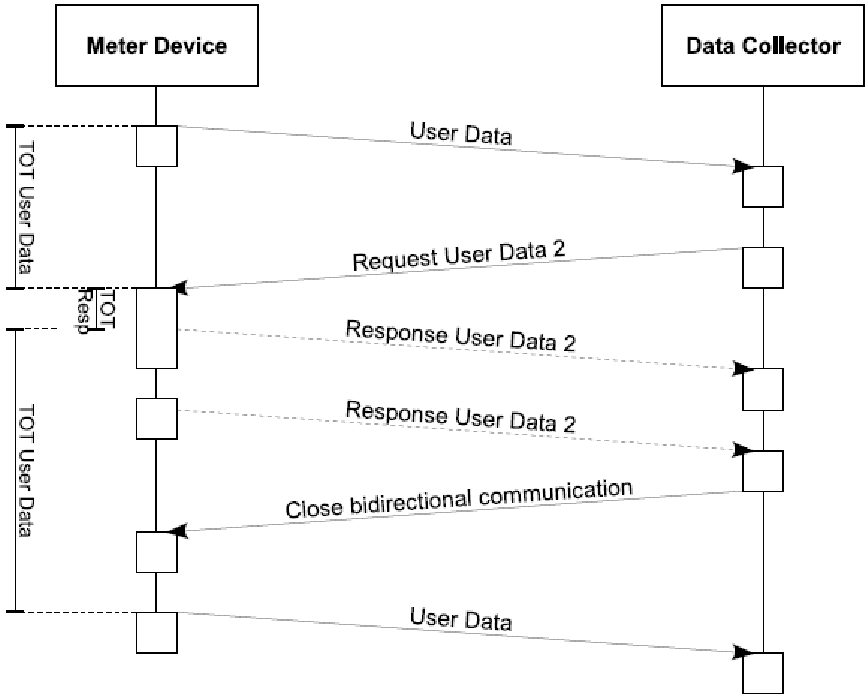

Figure 2 – Bidirectional Communication (adapted from [13]).

The max timeouts of bidirectional communication are shown in Figure 2. The listening time of 3ms is set. The packets have to be prepared in outgoing buffers to be sent immediately after receiving an access demand request. Other time intervals are not defined in the specification, e.g. the power-down periods of the metering device. So, those parameters have to be set to reasonable values in order to combine periodical data transfer and low power operation.

2.2.3 Telegram Formats

The telegram formats are three, identified by Table 5.

Table 5 – M-Bus Telegram Formats (adapted from [14]).

Byte	Single Character (HEX)	Short Telegram (HEX)	Long Telegram (HEX)
1	E5h	Start 10h	Start 68h
2		C Field	L Field
3		A Field	L Field (Repetition)
4		CS (Checksum)	Start 68h
5		Stop 16h	C Field
6			A Field
7			CI Field
8 - YY			Data (0 – 52 Bytes)
YY + 1			CS (Checksum)
YY + 2			Stop 16h

- **Single Character**: This telegram format consists of the single character E5h and is used to acknowledge the telegram received.
- **Short Telegram**: This telegram is identified by the start character 10h and consists of five characters. It’s used by the M-BUS Master to command the transmission of data from the M-BUS Slave.
- **Long Telegram**: This telegram is identified by the start character 68h and consists of a variable number of characters, in which the active data are also present. It is used by the M-BUS Master to transmit commands to the M-BUS Slave, and by the M-BUS Slave to send the read-out Data to the M-BUS Master.

C-Field

As can be seen in Table 6, the Control Field (C-Field) contains information on the direction of the exchange of communication, the success of the actual operation of communication and the proper function of the telegram.

Table 6 – C-Field Bit Division (adapted from [14]).

	RES	**PRM**	**FCB/ACD**	**FCV/DFC**	**Function**			
Bit Number	7	6	5	4	3	2	1	0
Master → Slave	0	1	FCB	FCV	F3	F2	F1	F0
Slave → Master	0	0	ACD	DFC	F3	F2	F1	F0

The **RES** (Reserved) is a reserved bit and should be set to 0.

The **PRM** (Primary Message) indicates where the frame is being sent. If it is set to 1 the communication has the direction Master for Slave; vice versa it is set to 0.

In the Master for Slave direction, if the frame count bit valid (**FCV** – Bit #4) is set to 1, then the frame count bit (**FCB** – Bit #5) has not to be ignored.

The **FCB** (Frame Count Bit) is used to indicate successful transmission procedure. A Master shall toggle the bit after a successful reception of a reply from the Slave. After this, if the Slave answer is multi-telegram, the Slave has to send the next telegram of the multi-telegram answer.

If the expected reply is missing, or the reception faults, the master resends the same telegram with the same **FCB**.

FCV (Frame Count Valid) in frames sent from a primary station indicates whether the duplication detection mechanism of the frame count bit is used (when set to 1) or not (when set to 0).

The **ACD** (Access Demand), if set to 1, indicates that the sending secondary station has high priority data available, which should be requested by the primary station.

In the Slave for Master direction, both these bits can undertake other tasks. The **DFC** (Data Flow Control) serves to control the flow of data, in that the slave with a DFC=1 indicates that it can accept no further data.

The **DFC**, if set to 1, indicates that the sending secondary station may not be able to process further frames sent by the primary station; it can be used as a flow control mechanism to prevent data overflow at the secondary station.

Function is a numeric code indicating the type of frame being sent; its meaning depends on the direction of communication (master to slave or vice versa).

A-Field

The Address Field (A-Field) is used to address the recipient in the calling direction, and to identify the sender of information in the receiving direction.

The size of this field is one byte, and it can assume the value between 0 – 255, divided as shown in Table 7.

Table 7 – Value of A-Field (adapted from [14]).

A Field (HEX)	Primary Address	Remarks
00	0	Default Address Given by Manufacturer
01 – FA	1 - 250	Primary Address Settable
FB, FC	251, 252	Reserved for Future Use
FD	253	Used for Secondary Address Procedures
FE	254	Use to Transmit Information to All Participants in the M-BUS System
FF	255	Use to Transmit Information to All Participants in the M-BUS System

Using the address 254 (FEh) every Slave answer with the acknowledging (E5h) or with their primary address.

Using the address 255 (FFh) no one Slave replies.

CI-Field

The Control Information (CI-Field) contains information for the receiver of the telegram. It provides values for upper layers, time service, alarm service and abstract types such as the network or extended link layer. Some interesting ones are:

- **Response from device** is used to signal data records being submitted. An example for such data is the consumption value.
- **Command to device** could be used to, for example, remotely open or close a valve or breaker.
- **Error from device** is used to signal errors in the application layer to the peer. Errors could be: command unknown, encryption method unsupported, decryption failed, access denied. A full list of errors is provided in the dedicated

application layer [6].

- **Alarm from device** is used to notify the peer about unusual occurrences such as power low or issues that would require a service action such as triggered tamper switches or permanent failure of part of the hardware.
- **Time sync to device** is used in order to update the time service within the device. Time sync to device is also referred to as Clock synchronization within the standard.
- **Application reset** does, depending on the implementation, reset application values such as consumption, history, tariff, instantaneous, calibration or load management values.

L-Field

The Length Field (L-Field) defines the number of bytes (expressed in hex value) of the Active Data making up the telegram, plus 3byte for the C, A and Cl-Fields. This field is always transmitted twice in Long Telegrams.

CS-Field (Checksum)

The Checksum (CS-Field) serves to recognize transmission and synchronization faults, and is configured from specific parts of telegram. The checksum is calculated from the arithmetical sum of the data mentioned above plus the Active Data.

2.2.4 Communications Process

Having described the basic structure of a WM-Bus message, we move on to describe how a meter communicates with a gateway. There are several ways a meter can communicate with a collector. In Table 8, we can see the different kinds of messages exchanged in connection with the C-field. In Table 8 we can also see the different functions of the messages, their direction, as well as their confirmation messages.

Table 8 – C-Field of the commands used (adapted from [14]).

Telegram Name	C Field (BIN)	C Field (HEX)	Telegram	Description
SND_NKE	0100 0000	40	Short Frame	Initialization of the Slave
SND_UD	01F1 10011	53 / 73	Long Frame	Master send data to Slave
REQ_UD2	01F1 11011	5B / 7B	Short Frame	Master requests Class 2 Data to Slave
REQ_UD1	01F1 1010	5A / 7A	Long Frame	Master requests Class 1 Data to Slave
RSP_UD	00AD 1000	08 / 18	Long Frame	Data transfer from Slave to Master

The WM-BUS module accepts two kinds of transmission:

Send / Confirm > SND / CON

Request / Respond > REQ / RSP

A standard straight communication between M-BUS Master and M-BUS Slave is:

MASTER		SLAVE
SND_NKE	>	E5h
SND_UD	>	E5h
REQ_UD2	>	RSP_UD

An WM-BUS communication we can have different messages between the meter and the collector. They are as follows:

SND_NKE: This procedure serves to start up after an interruption or beginning of communication. If the Slave was selected for secondary addressing, it will be deselected.

The value of the frame count bit FCB is cleared in the Slave, i.e. it expects that the first telegram from a Master with FCV = 1, has the FCB = 1. The Slave confirms a correct reception of the telegram with the single character acknowledge (E5h) or omits the answer if it didn’t receive the telegram correctly. Mandatory for modes S2, T2, C2, R2, N2, F2.

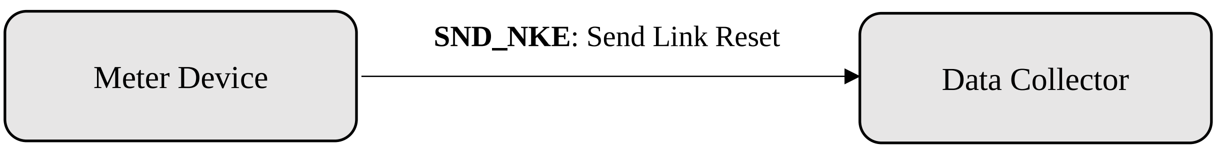

Figure 3 – SND_NKE Transaction.

SND_NR: The meter sends on-demand/periodical application data without request (Send/No Reply). Doesn’t need confirmation from collector. Mandatory for modes S1, N1.

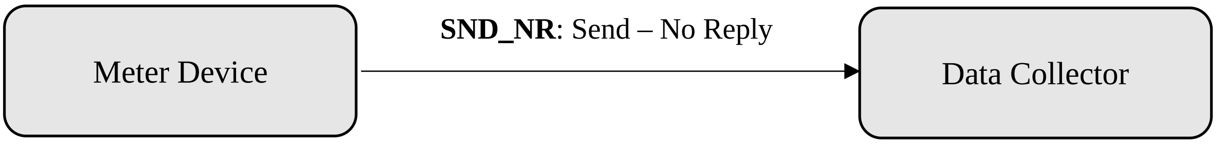

Figure 4 – SND_NR Transaction.

ACC_NR: The meter sends on-demand/periodical message to provide the opportunity of access to itself (contains no application data).

Figure 5 – ACC_NR Transaction.

SND_IR: The meter sends manually initiated installation data (Send Installation Request). Confirmed by CNF_IR.

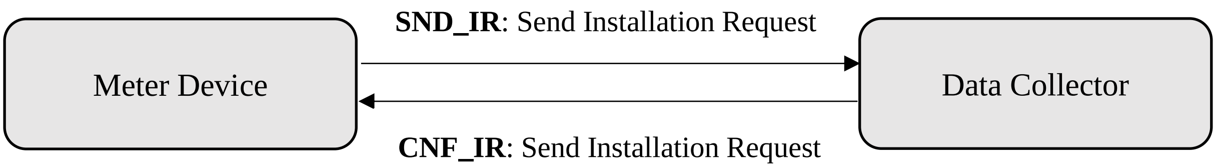

Figure 6 – SND_IR/CNF_IR Transaction.

CNF_IR: Confirms the successful registration (installation) of meter to service tool, contains no application data).

SND_UD / SND_UD2: This procedure is used to send user data to the M-BUS Slave. The Slave confirms a correct reception of the telegram with the single character acknowledge (E5h) or omits the answer if it didn’t receive the telegram correctly.

If “other” sends a SND_UD, it sends a command to the meter. The meter responds with an ACK, depending on the SND_UD content. If the collector sends a SND_UD2 (SND_UD with C-Field=43h), it sends a command to the meter but the meter assumes that it has received a subsequent REQ_UD2. In that case it won’t respond with an ACK but with RSP_UD, instead.

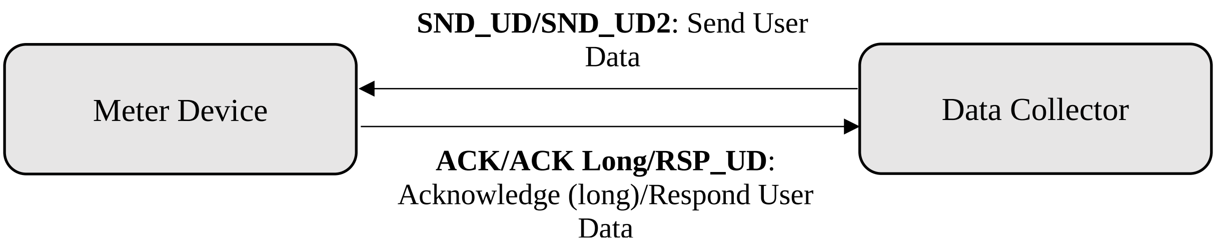

Figure 7 – SND_UD / ACK, RSP_UD Transaction.

ACK / ACK long: Acknowledgement from the meter to the collector of user data.

REQ-UD1 / REQ-UD2: This procedure is used by the M-BUS Master to receive data to the M-BUS Slave.

If Master sends a REQ-UD1, it means that it requests alarm data from the meter. Thus the meter shall respond with RSP-UD, which will contain the desired information. If collector sends a REQ-UD2, it means that it requests data from the meter. Then, the meter will again answer with RSP-UD (if the meter doesn't support alarm data, it responds with an ACK).

The meter sends the data requested by SND_UD command.

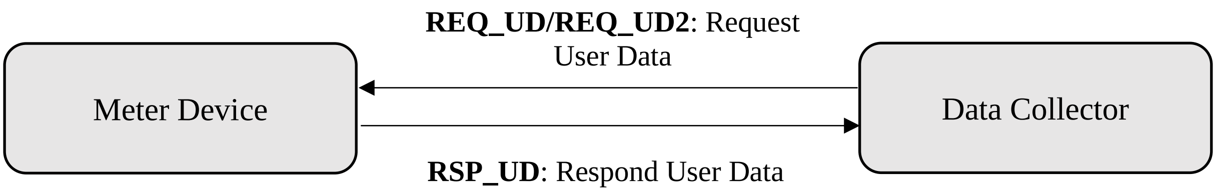

Figure 8 – REQ_UD / RSP_UD Transaction.

RSP_UD: This procedure is used by the meter to send the requested data to the collector.

ACC_DMD: Access demand from meter to collector. This message requests an access to the meter (contains no application data).

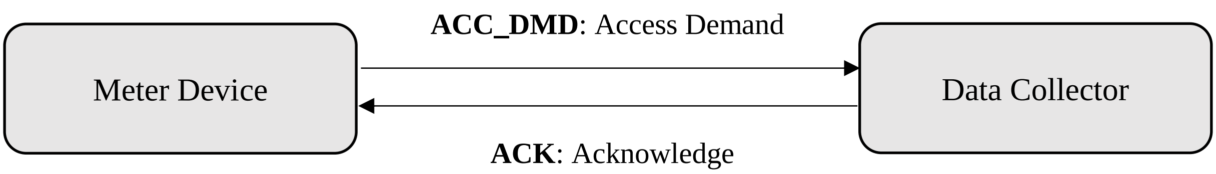

Figure 9 – ACC_CMD / ACK Transaction.

ACK: Acknowledgement from the meter to the collector.

2.2.5 Frame Description

The WM-Bus link layer is compliant with EN 13757-4. It provides services that transfer data between PHY and application layer, generates outgoing CRC (Cyclic redundancy check), and verifies CRCs for incoming messages. Further, the link layer provides WM-Bus addressing, acknowledges transfers for bidirectional communication modes, deals with WM-Bus frame formation, and verification of incoming frames. Two frame formats are foreseen, named A and B, identified by a specific preamble/synch sequence. The standard provides a number of predefined messages that are not used to carry application-specific data (that depend, for example, on the specific sensor used to monitor the grid), but to manage operational conditions.

Once registered, the meter automatically leaves the installation mode, whereas the concentrator requires manual intervention or timeout. The advantages of the 169MHz band with respect to the 868MHz are implicitly related to the narrowband transmission concept. The greater the bandwidth, the greater the noise at the receiver input: so, with a signal bandwidth of 25kHz or less, the N mode introduces much higher link budget and provides longer range solutions than the ones allowed at 868MHz. In the band of 868MHz multiple communication modes exist with data rates of 32,768 and 100kchip/s and bandwidth of 100 and 270kHz, respectively [15].

A narrowband solution results in a radio performance improvement without significant problems, because the amount of data to be transmitted in a metering scenario is very low, thus avoiding bottlenecks that would slow down the entire network performance. The WM-Bus protocol also foresees the division of the available bandwidth in a number of channels. Up to six channels can be allocated for the data exchange between meter and concentrator, spaced by 12,5kHz. If only one channel is not sufficient to meet the bandwidth requirements, it is possible to consider the simultaneous use of more channels within the same interference domain.

- **Frame Format A**

The preamble is used for synchronization between transmitter and receiver. The EN 13757-4 specification imposes a minimum limit for preamble length, which depends on the mode used. In mode N, the preamble length depends on the modulation used (4 bytes for GFSK and GMSK, 8 bytes for 4 GFSK).

Frame format A, Figure 10, foresees a 2 byte CRC which is specified by a polynomial [11]. The first block of the frame format is fixed length and contains the sender's address. The second and any following block's length depend on the user data size.

First Block					Second Block			Optional Block	
Length	Ctrl	Manuf. ID	Address	CRC	Ctrl. Info	Data	CRC	Data	CRC
1 byte	1 byte	2 bytes	6 bytes	2 bytes	1 byte	max. 15 bytes	2 bytes	max. 16 bytes each	2 bytes

Figure 10 – WM-Bus Frame Format A (adapted from [11]).

The Manufacturer ID field (M-Field) shall contain a unique User/Manufacturer ID of the sender. If the most significant bit of these two bytes User/Manufacturer ID is equal to zero, then the address A, shall be a unique (hard coded) manufacturer meter address of 6 bytes. Each manufacturer is responsible for the worldwide uniqueness of these 6 bytes. Any type of coding or numbering, including type/version/date may be used as long as the ID is unique. If the most significant bit of this two-byte User/Manufacturer ID is different from zero, then the 6 byte address shall be unique at least within the maximum transmission range of the system. This address is usually assigned to the device at installation time. As long as these unique address requirements are fulfilled, the remaining bytes may be used for user specific purposes.

The CRC-field Cyclic Redundancy Check) is for verification of the received data. It is calculated over the block where it is contained. The CRC polynomial is $x^{16} + x^{13} + x^{12} + x^{11} + x^{10} + x^{8} + x^{6} + x^{5} + x^{2} + 1$ with initial value 0.

The first block of frame format A, as shown in Figure 11, is nearly identical to the first block in frame format B.

- **Frame Format B**

As with frame format A, the first block or frame header is fixed length and the length of the subsequent blocks depends on the payload. As mentioned, the first block does not contain a CRC in format B.

First Block				Second Block			Optional Block	
Length	Ctrl	Manuf. ID	Address	Ctrl. Info	Data	CRC	Data	CRC
1 byte	1 byte	2 bytes	6 bytes	1 byte	max. 115 bytes	2 bytes	max. 126 bytes	2 bytes

Figure 11 – WM-Bus Frame Format B (adapted from [11]).

The first block fields do contain the frame length, a control byte to signal message direction and purpose, the manufacturer identification and the device address. Frame format B is used in Modes C and F, so we will not be analyzing this frame format.

Analyzing the first block of a captured message will provide some insights into the common contents of a real world WM-Bus frame, Figure 12.

Timestamp;Frame
06.02.2013 13:40:20:518;**1E 44 2D 2C 07 71 94 15 01 02** 7A B3 00 10 85 BF 5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8

Figure 12 – WM-Bus Frame Capture, Firs Block Contents.

To make the WM-Bus system function with more WM-Bus modules connected, it is necessary to distinguish between the individual WM-Bus modules. This is done by WM-Bus ID numbers of each WM-Bus module.

The first ten bytes of the captured frame identify a WM-BUS module. Each field is interpreted in Table 9.

Table 9 – WM-Bus Frame B Capture, Data Decoded First Block (adapted from [11]).

Field	Value (hex)	Interpretation
Length	1E	Indicates the number of subsequent user data bytes including the control and address bytes and excluding the CRC.
Control	44	Indicates message from primary station, function send/no reply (SND-NR)
Manufacturer ID	2D 2C	Unique User/Manufacturer ID of the sender
Address	07 71 94 15 01 02	Indicates unique sender address Most significant bit of the Manufacturer ID indicates a globally unique address. Identification: 15 94 71 07 (low byte first, 4 bytes) Device Type: 02 (byte) Version: 01 (1 byte)

2.2.6 Transport Layer and Data Header

The transport layer is briefly outlined within the “Wireless meter readout” part of the WM-Bus standard series. However, since the WM-Bus stack does omit the ISO/OSI layers three to six, the “transport layer” structure is defined in the dedicated application layer part of the standard whereas the application layer refers to the transport layer as the data header. The data header pretending the data records will be embedded into the frames data section. Actually, there are three different types of data headers whereby all of them have been observed within the lab environment.

- **No Header**

The CI-field signals 78h than there is no data header available. Following that, encryption of data records is not supported. This field is extension from the EN 1434-3 [16]. It is recommended for new master implementations to simplify the integration of radio based communication.

- **Short Data Header**

The short data header (4 bytes and CI=7Ah) defines an access number, status byte and a configuration word as outlined in Figure 13. The specification distinguishes between frames originating at the meter or originating from others. Hence, contents of the data header fields slightly differ depending on the communication direction, type and configuration. The descriptions of Table 10 only provide brief description of each field.

Access	Status	Configuration
1 byte	1byte	2 bytes

Figure 13 – Short Data Header Format (adapted from [11]).

Table 10 – WM-Bus Frame Capture, Data Decoded Header (adapted from [11]).

Field	Value (hex)	Interpretation
Access number	B3	Current access number is 179. The standard mandates to choose a random number on meter start.
Status field	00	The message is meter initiated and there are no alarms or errors.
Configuration	10 85	Encryption mode is 5_h which is AES-128 in CBC mode. The configuration word further indicates (10_h) a single encrypted block containing meter data (without signature). The field further indicates a short window where the meter listens for requests (8_h).

Decoding the data header allows for a closer look at the data records. However, the records need to be decrypted before analysis according to the M-Bus data records specification. The encryption process will be described later on.

Access number (ACC) contains a number which is intended to support the detection of repeated frames and should be incremented for each new frame except for responses where the response should reflect the received value. The standard clearly states that this mechanism does not provide sufficient prevention against replay attacks and suggests use of additional measures within the data layer to counter replay.

Status field is included if the frame originated from the meter than this field indicates various alerts and errors. If it originated from any other device then it should provide the receive signal strength indicator (RSSI) of last received meter frame to keep the meter informed about the link quality.

Configuration field is used to set the encryption mode and to define the length of the encrypted user data. The field can be used to choose between DES in CBC mode or AES-128 in CBC mode which both can be used with or without zero IV. The standard clearly states that DES is deprecated and should not be used for new developments any more. None of the devices in the lab supported DES encryption. Depending on the encryption mode, the configuration field provides supplemental information such as the encrypted content length, whether the contained data comes with a signature or the hop count for data that passed a repeater and access control.

All of the described three fields also exist in the long data header format. The long data header defines some additional fields to support wireless to wired bridging respectively to signal addresses of wired devices to a wireless collector

- **Long Data Header**

The long data header (12 bytes and CI = 72h) inherits all the fields of the short data header. Additionally it provides fields for device identification, a manufacturer ID, a version ID and a device type ID. Figure 14 show the format of Long Data Header.

Identification	Manufacturer	Version	Dev. Type	Access	Status	Configuration
4 byte	2 byte	1 byte	1 byte	1 byte	1 byte	2 bytes

Figure 14 – Long Data Header Format (adapted from [11]).

The long data header defines that the identification within the long header shall have precedence over the frame address.

2.3 System Architecture

The WM-Bus favors asymmetric network topologies with low-cost or low-power metering devices on the one side and data collectors with higher performance on the other side. Currently, only point-to-point or star network topologies can be supported.

Nowadays, the technological factors, such as increasing the reliability of the technology, a significant increase in lifetime of the batteries, the technological development level measurement and control equipment, decisively contributed to the application of domiciliary telemetry systems.

From the point of view of suppliers, the need to reduce the estimate of readings, improve service quality and reduce costs involved in the removal of the readings are important factors. Typical communication architecture for domiciliary telemetry systems is based on a hierarchical topology, as the one shown in Figure 15. The meters nodes are connected to collector nodes, which in turn withdraw and send them to a centralized control and monitoring system, where the data are stored and processed.

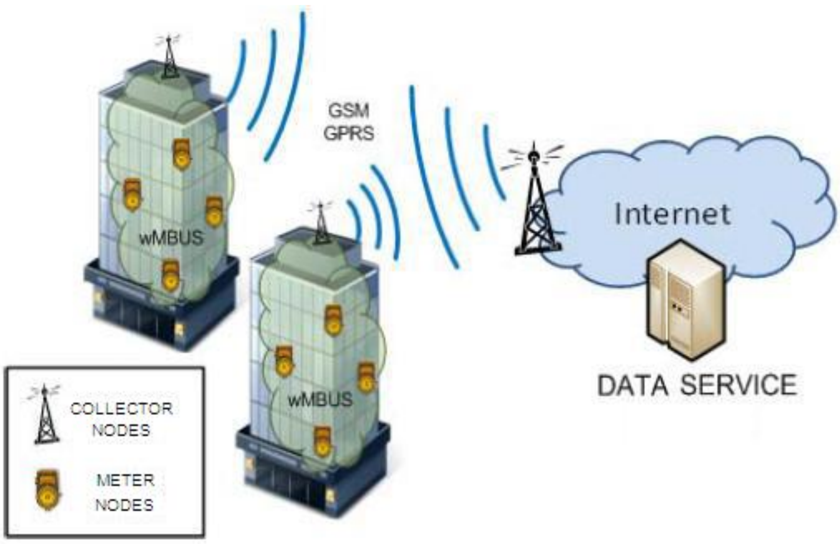

Figure 15 – Architecture of a Telemetry System (adapted from [17]).

The hierarchical topology relies on the assumption that peripheral nodes are able to perform short or medium range radio transmissions, at low power consumption. On the contrary, gateway nodes are typically equipped with long range transmission capabilities, up to a geographic scale. Data generated from several peripheral nodes are collected and organized by each gateway node, so that they can be delivered to the central monitoring unit, where they are processed by suitable algorithms, to identify and locate possible faults, in a real time fashion.

The architecture proposed for the monitoring network assumes collectors nodes equipped with GSM/GPRS modules. In fact, collector’s nodes that collect monitoring-related data from multiple meter nodes must be able to deliver them to the central unit, typically along distances of a few kilometers. Long range transmissions generated by collector’s nodes are sustained by power supplied from the network, or from solar cells; short/medium range communications, as those of meter nodes, must require the minimum power consumption, usually provided by batteries. At the same time, in order to limit the overall costs related to the network deployment, the number of meters nodes should be somehow kept small. Based on the analysis of these requirements, the WM-Bus standards is assumed as a good tradeoff among the power needs due to radio transmission and the minimum coverage range necessary to limit the number of sensor nodes that shall be located along the network.

Chapter 3

WM-Bus Coverage

This section describes the propagation model selected and used. The evaluation of WM-Bus transmission coverage has been performed resorting to classical analytical models used to estimate the signal attenuation in different environments.

Aspects, such as maximum number of users and coexistence between different services, are way more important than data throughput or delays, when analyzing metering networks performance. Given the lack of media access control methods in WM-Bus, the standard just allows to prevent systematic collision through a cyclic access number that, randomly initialized on each device, allows slight time variation between two subsequent transmissions.

3.1 Channelization aspects

The WM-Bus is a European communication protocol that has been specified for metering applications (the “M” of M-Bus stands for “metering”). Mode “N” has been specified in order to allow communication at higher range than the typical home area situations; in this case a lower frequency (the 75kHz band between 169,400 and 169,475MHz has been identified). This frequency band has been reserved by European Telecommunication Standardization Institute (ETSI) for metering applications allowing a maximum power of 500mW (27dBm) with a maximum duty-cycle of 10% [15].

The wireless transmission is narrowband and it uses a Gaussian Frequency Shift Keying (GFSK) modulation at different data-rates according to 6 different channels; those channels are spaced by 12,5kHz and have a bit-rate either of 4,8kbps or of 2,4kbps. However the Mode N2g that uses a 4GFSK modulation has been reserved for “relaying” type of communication nodes. Different service classes are defined within the standard and in the higher class a minimum level of sensitivity of -120dBm shall be guaranteed at a Packet Error Rate (PER) $< 10^{-2}$.

The Frequency Division Multiplexing (FDM) is exposed to potential adjacent channel interference phenomena, however, the filters onboard of the WM-Bus transceivers are more than capable to reduce the interfering signal power level 20dB lower than the power level of the channel central frequency.

3.2 Evaluation of maximum transmission coverage

One of the main advantages of the WM-Bus mode N protocol is the use of a low transmission frequency, which should make it possible to achieve greater Line-of-Sight (LOS) distances and less sensitivity to attenuation due to obstacles. In a typical scenario, the meters are installed in specific locations protected by metal cabinets. The goal is to define some parameters that allow evaluate coverage perform, with good approximation, taking into account those radio propagation aspects.

Although the majority of the meters are placed at ground level, in some cases, devices such as water metering device, are located in the basement.

In case of a multiservice network, one data concentrator should be deployed to serve not only electricity meters, but different services with their own radio propagation specific issues. The radio coverage assured by the data concentrator (the maximum communication range) should be studied according to the most critical path that could be present between the concentrator and the reading/metering devices.

A propagation model is used to quantify the maximum propagation loss between the transmitter and the receiver in both directions of propagation, to estimate the coverage radius, so to know the maximum range of a radio link, and therefore used to compute the number of concentrators required to cover a particular city area.

There is no generic application model for all kinds of environments, frequencies and parameters, thus are used hybrid models that include the characteristics of both theoretical models and empirical. These models can be calculated with real measurements in specific propagation environments where they are used. Therefore, minimizes the error between the signal estimation provided by the propagation model and the subsequent reality with the physical implementation. However, the application of models with an empirical component requires the environment classification. In this sense it stands out three broad categories:

- Rural;
- Suburban;
- Urban.

The propagation models currently used in the planning of mobile systems are hybrid models and include empirical and theoretical perspectives. These models are based on empirical formulas derived from experimental measurements.

There are several types of classifications, usually associated with different propagation models. The environments classification considers the following parameters:

- Ripple Land;
- Density of the vegetation;
- Density and height of buildings;
- Existence of open areas;
- Existence of water surfaces.

The attenuation and reflection vary according to the materials of construction. The existence of roads leading to guided propagation phenomena with different characteristics in the radial and in the circumferential streets. The proximity of buildings to each other can lead to high errors in the application of the propagation models.

Due to these characteristics, the measurement task of propagation model based on actual measurements is extraordinarily difficult and usually occurs significant deviation between the signal prediction and reality subsequently implemented.

Based on that, it described to follow the most appropriate model to use the WM-Bus network, being the Okumura-Hata model.

3.3 Propagation Model

The Okumura-Hata model presents the results in the form of curves. Hata in 1980 established expressions approaching some of these curves. Two large-scale tests were carried out between 1962 and 1965 with several broadcasters transmitting in several bands in a variety of propagation environments, trying to explore the fundamental factors that influence the spread from the morphology of the terrain to the existence of buildings, street orientation, existence of open areas, aquatic areas, etc... [16].

The Okumura-Hata model is used for planning cellular networks to predict the behavior of the channel in the band [150, 2000]MHz for cell radius between 1 and 20 km.

Once the WM-Bus operates in the 169MHz, this model can be used. The formula to calculate the Path Loss (PL) is given by equation (3.1),

$$PL_{[\mathrm{dB}]} = A + B \times \log\left(d_{[\mathrm{km}]}\right) + C \tag{3.1}$$

where A is the attenuation parameter, calculated using equation (3.2), parameter B is given by equation (3.3) and parameter C ($\sum K_{correction}$) represents the correction factors to be applied to the environment and the type of terrain flee standard conditions referenced to the model (urban areas almost flat ground).

$$A = 69.55 + 26.16 \log\left(f_{[\mathrm{MHz}]}\right) - 13.82 \log\left(h_{c[\mathrm{m}]}\right) - Hmu_{[\mathrm{dB}]}(h_e, f) \tag{3.2}$$

$$B = 44.9 - 6.55\, log(h_{c[\mathrm{m}]}) \tag{3.3}$$

Where:

- d – Distance between transmitter and receiver, $d \in [1\ ,20]$km;
- f – Frequency, $f \in [150\ ,1500]$MHz;
- h_c – Collector Antenna Height, $h_c \in [30\ ,200]$m;
- h_e – Endpoint Antenna Height, $h_e \in [1\ ,10]$m;
- Hmu – Correction factor of the endpoint antenna height, expressed in dB.

The variable C and the Hmu parameter depend on the type of environment considered in planning.

Okumura classifies the different types of environments in 3 classes:

- Urban area – area with a high density of buildings, each having over eight floors;
- Suburban area – Some obstacles, not very dense in the region in front of the mobile terminal;
- Rural / open area – Absence of obstacles in a region between 300m and 400m in front of the handset. Almost open area is defined as the middle ground between suburban and open areas.

Urban Areas

In an urban environment with the existence of buildings, will lead to the existence of many reflected rays causing fading, and areas where the attenuation is great.

$$Hmu_{[\mathrm{dB}]}(h_e, f) = \begin{cases} 3.2\ [\log(11.75 \times h_e)]^2 - 4.97\ , f \geq 400\ \mathrm{MHz}, \\ 8.29 \times [\log(1.54 \times h_e)^2] - 1.1], f \leq 200\ \mathrm{MHz} \end{cases} \quad (3.4)$$

$$C_{[dB]} = 0$$

Suburban

$$Hmu_{[\mathrm{dB}]}(h_e, f) = \left[1.1\ \log(f_{[\mathrm{MHz}]}) - 0.7\right] \times h_e - \left[1.56\ \log\left(f_{[\mathrm{MHz}]}\right) - 0.8\right] \quad (3.5)$$

$$C_{[\mathrm{dB}]} = -2\left[\log\left(\frac{f_{[\mathrm{MHz}]}}{28}\right)^2 - 5.4\right]\ ,\ Suburban \quad (3.6)$$

Rural

$$Hmu_{[\mathrm{dB}]}(h_e, f) = \left[1.1\ \log(f_{[\mathrm{MHz}]}) - 0.7\right] \times h_e - \left[1.56\ \log(f_{[\mathrm{MHz}]}) - 0.8\right] \quad (3.7)$$

$$C_{[\mathrm{dB}]} = -18.33 \log(f_{[\mathrm{MHz}]}) + 4.78 \left[\log(f_{[\mathrm{MHz}]})\right]^2 + 40.98\,,\ Rural \quad (3.8)$$

Equation (3.1) computes the distance.

$$R_{[\mathrm{km}]} = 10^{\frac{PL-A-C}{B}} \quad (3.9)$$

The cell radius estimates the distance between data collectors and meters, allowing estimating the number of data collectors required to cover a certain geographic area.

In most developed propagation models for predicting propagation loss in urban, suburban and rural environments, the propagation loss increases with distance

3.3.1 Correction factors

The environmental and terrain correction factors are applied to optimize and improve model accuracy when these parameters differ from the reference (almost flat terrain, urban area). The results of these factors were developed by Okumura and made available in a graphical format. The expressions that follow represent a good approximation of the curves Okumura.

- Rolling terrain, K_{th}, and position the handset in the rolling terrain, $\pm K_{hp}$

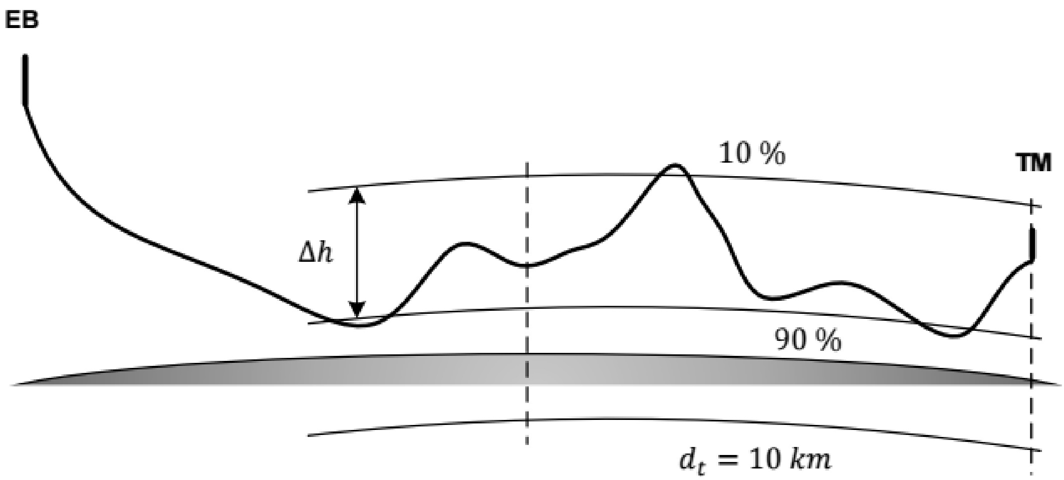

Figure 16 – Rolling terrain (adapted from [19]).

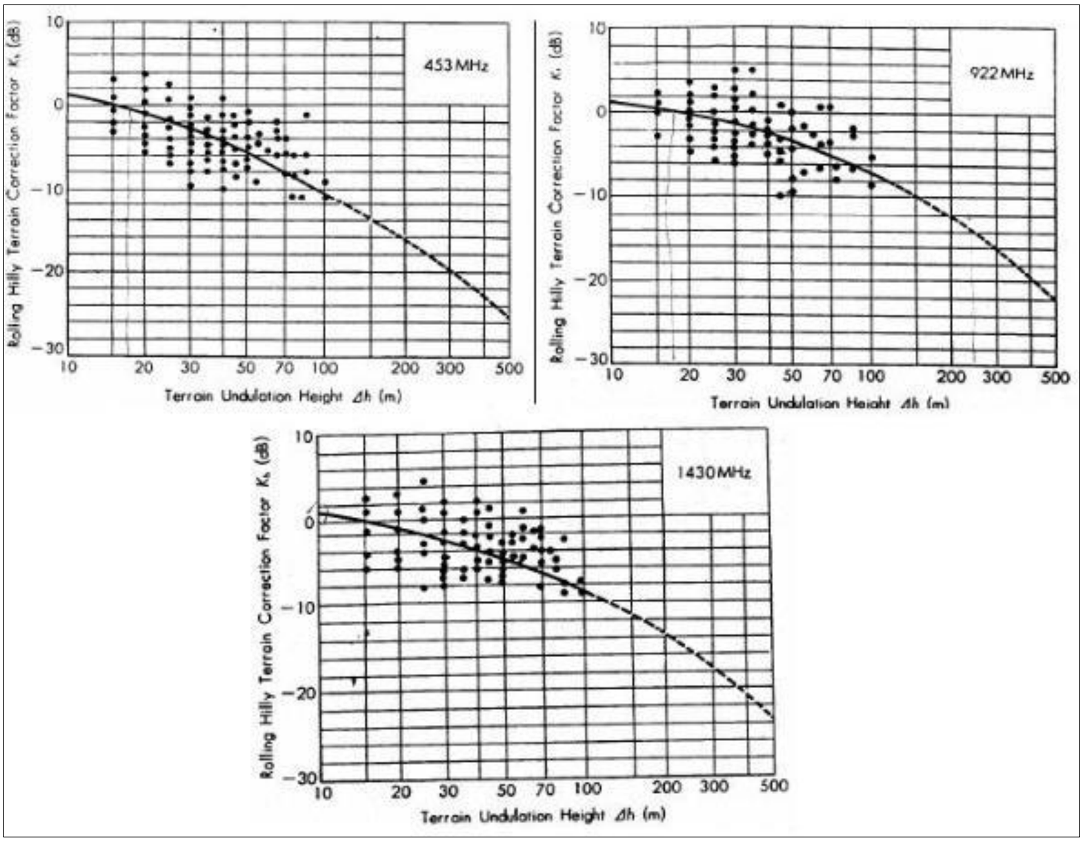

Figure 17 – Correction for the ripple of the terrain (adapted from [18]).

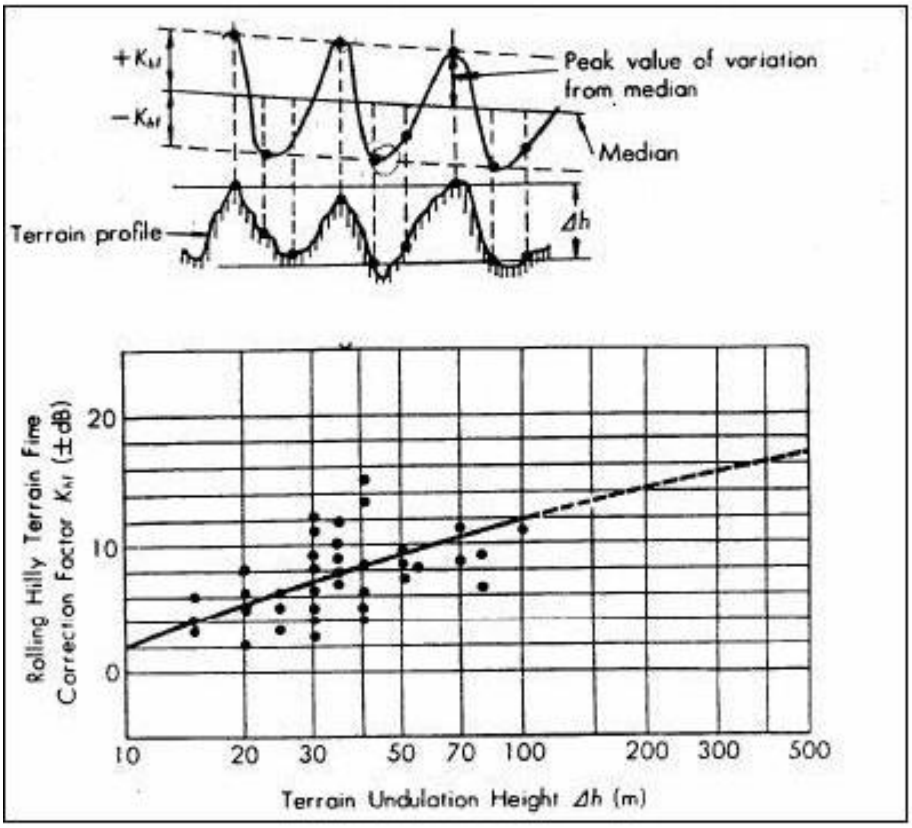

Figure 18 – Correction to the position in rolling terrain (adapted from [18]).

$$K_{th}(\Delta h)_{[dB]} = \begin{cases} -8log^2(\Delta h_{[m]}) + 12log(\Delta h_{[m]}) - 3, & f = 453\ MHz \\ -8log^2(\Delta h_{[m]}) + 16log(\Delta h_{[m]}) - 7, & f = 922\ MHz \\ -8log^2(\Delta h_{[m]}) - 0.5log(\Delta h_{[m]}) - 4.5, & f = 1430\ MHz \end{cases} \quad (3.10)$$

$$K_{hp}(\Delta h)_{[dB]} = -2log^2(\Delta h_{[m]}) + 16log(\Delta h_{[m]}) - 12 \quad (3.11)$$

The calculated field intensity may have to be adjusted according to the degree of irregularity on the ground along the path between the antennas. The field intensity decreases as a function of the ground roughness, so the height of the land waving. This height is defined as the difference between the value 10% below the maximum elevations, and the value 10% above the minimum of ground elevations, over a distance of 10 km.

Note that this correction factor is specified for 453, 922 and 1430MHz. Any frequency between 453 and 1430 MHz will be interpolated from these values. For frequencies outside this range, these are evaluated with curves of 453 and 1439MHz.

Another correction factor that can be included in the calculation of transmission losses is relative to position the handset on uneven ground. Thus, the field strength increases when the reception signal is made near the top of the hill (+K_{hp}) (highest point of the uneven ground), and decreases when the reception is made in the valleys (-K_{hp}).

- Average slope of the terrain

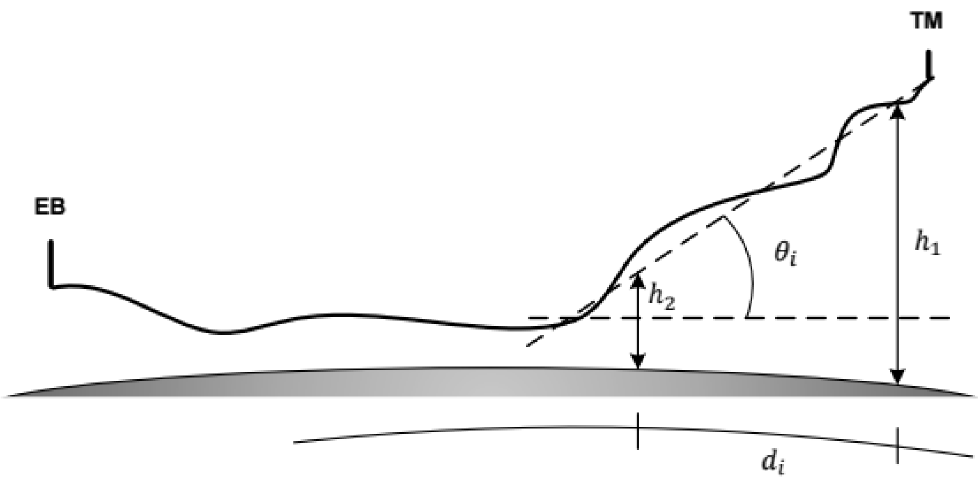

Figure 19 – Slope of the terrain (adapted from [19]).

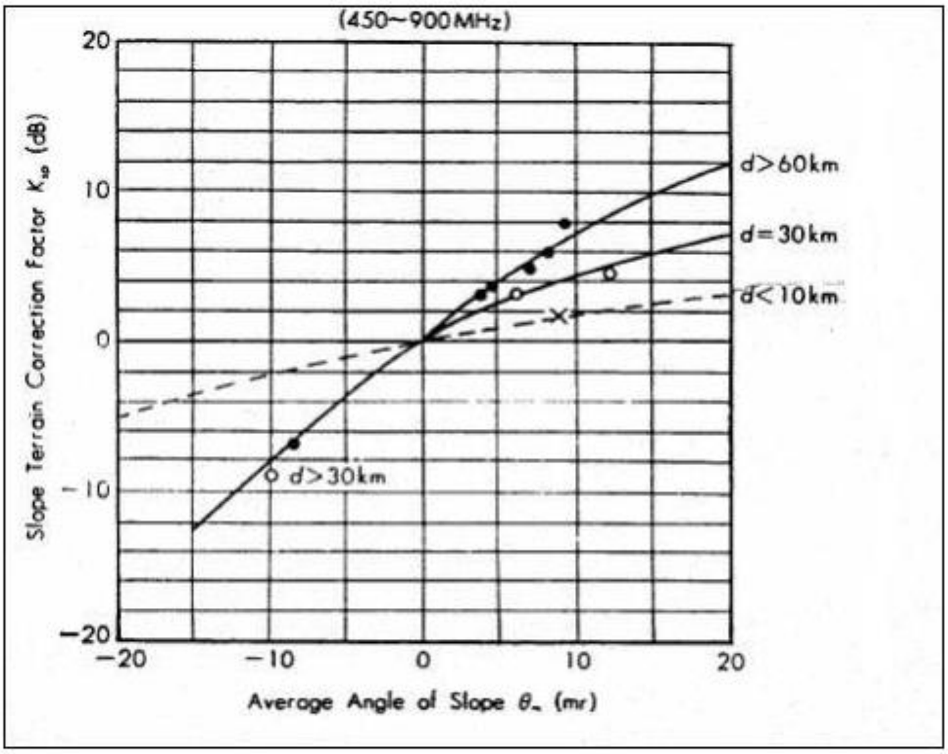

Figure 20 – Correction to the average slope of the terrain (adapted from [18]).

$$K_{sp}(\theta)_{[dB]} = \begin{cases} -0.0025\theta_{[mrad]}^2 + 0.204\theta_{[mrad]}, \quad d < 10\ km \\ -0.64|\theta|_{[mrad]}^{1.09}, \ d > 30km, -15mrad < \theta < 0mrad \\ -0.007\theta_{[mrad]}^2 + 0.5\theta_{[mrad]}, d = 40\ km, 0mrad < \theta < 20mrad \\ -0.012\theta_{[mrad]}^2 + 0.84\theta_{[mrad]}, d > 60\ km, 0mrad < \theta < 20mrad \end{cases} \quad (3.12)$$

In general, the intensity of the total field at the reception, increases in route upward sloping, and decreases to descendants routes. The route of the tilt angle and the corresponding adjustment of the field are calculated only for distances greater than 5km. The average tilt angle is determined point by point from the lowest base point to the place of reception. The computed mean angle is limited to boundaries of Figure 20, so angles calculated with magnitude greater than ± 20mrad, are evaluated in the figure limits, so ± 20mrad.

When this correction factor is included in other frequencies, it is not made any adjustments. Only applies in frequency between 450 and 900MHz.

- Mixed path land / sea, K_{mp}

$$\beta = d_s/d$$

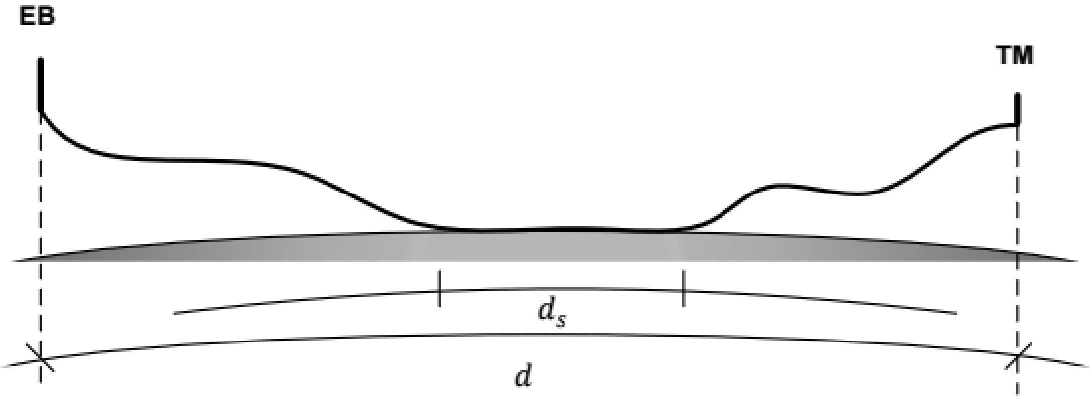

Figure 21 – Mixed path land / sea (adapted from [19]).

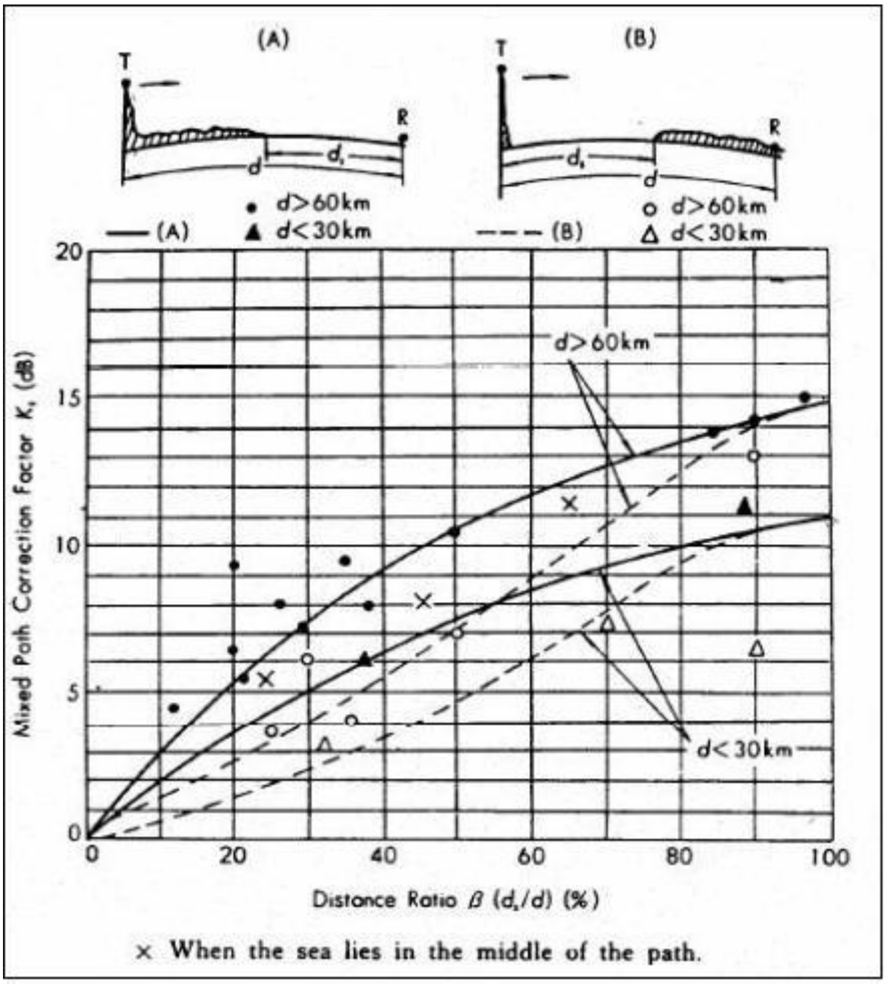

Figure 22 – Correction for mixed path (adapted from [18]).

$$K_{mp}(\beta)_{[dB]} = \begin{cases} \begin{cases} -12.4\beta^2 + 27.2\beta, & d > 60km \\ -8.0\beta^2 + 19.0\beta, & d < 30km \end{cases} & \{A \\ \begin{cases} 11.9\beta^2 + 4.7\beta, & d > 60km \\ 7.8\beta^2 + 5.6\beta, & d < 30km \end{cases} & \{B(\beta < 0.8) \end{cases} \quad (3.13)$$

In case B, the expressions are valid for B <0.8.

In mixed routes of land and sea, the intensity of the calculated field at the reception, increases with the parameter B. The scenario corresponds to the situation in which terrain with water is closest to the location where reception is made. In scenario B, the area occupied by water lying closer to the base station.

- Orientation of the streets and avenues in relation to the emitter K_{al}, K_{ac}

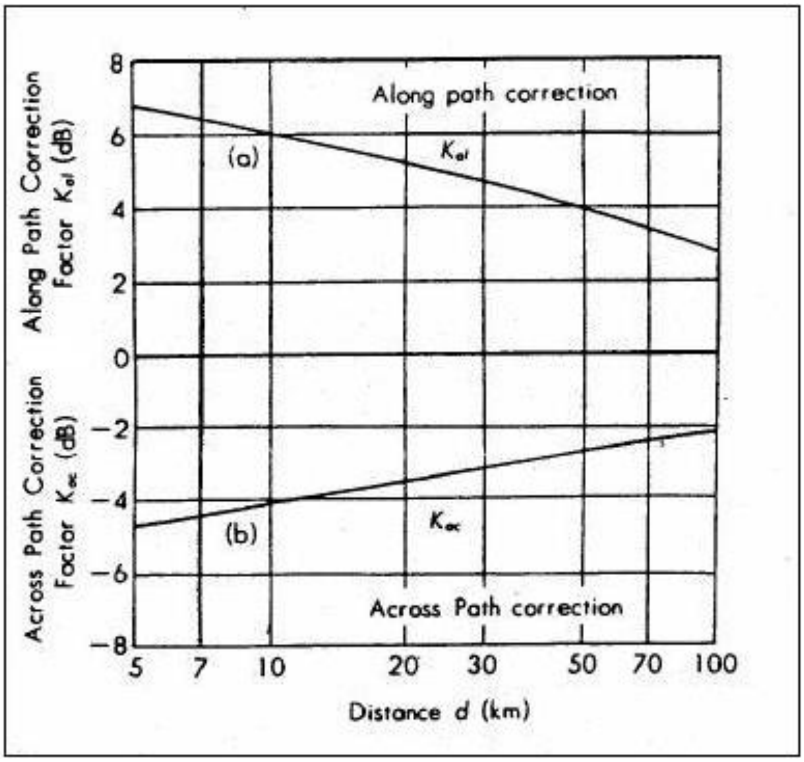

Figure 23 – Correction for orientation of the streets in relation to the emitter (adapted from [18]).

$$K_{ac}(d)_{[dB]} = 2.1\,log\left(d_{[km]}\right) - 6.3 \tag{3.14}$$

$$K_{al}(d)_{[dB]} = \begin{cases} -2.7\,log\left(d_{[km]}\right) + 8.6\,, & d \leq 40km \\ -4.0\,log\left(d_{[km]}\right) + 10.7\,, & d > 40km \end{cases} \tag{3.15}$$

The calculated field intensity of the reception may suffer a setting, according to the orientation of the transmitter relative to the streets. The field increases to receivers placed in streets which are arranged parallel to the direction of the waves emitted by the base station (K_{al}), and decreases when the streets are perpendicular (K_{ac}). For distances less than 5 km from the base station, the maximum values of Figure 23 (+6.71dB or -4.83 dB) are used.

The environmental correction factors given by the following expressions have been developed by Hata Okumura from the curves:

- Suburban areas

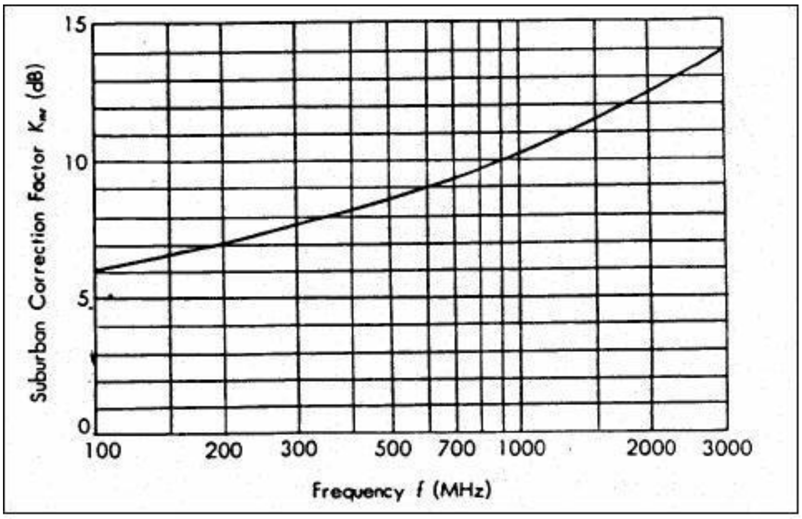

Figure 24 – Correction for suburban areas (adapted from [18]).

$$K_{su}(f)_{[dB]} = 2\,log^2\left(\frac{f_{[MHz]}}{28}\right) + 5.40 \tag{3.16}$$

- Open areas, (K_{oa}), or nearly open, (K_{qo})

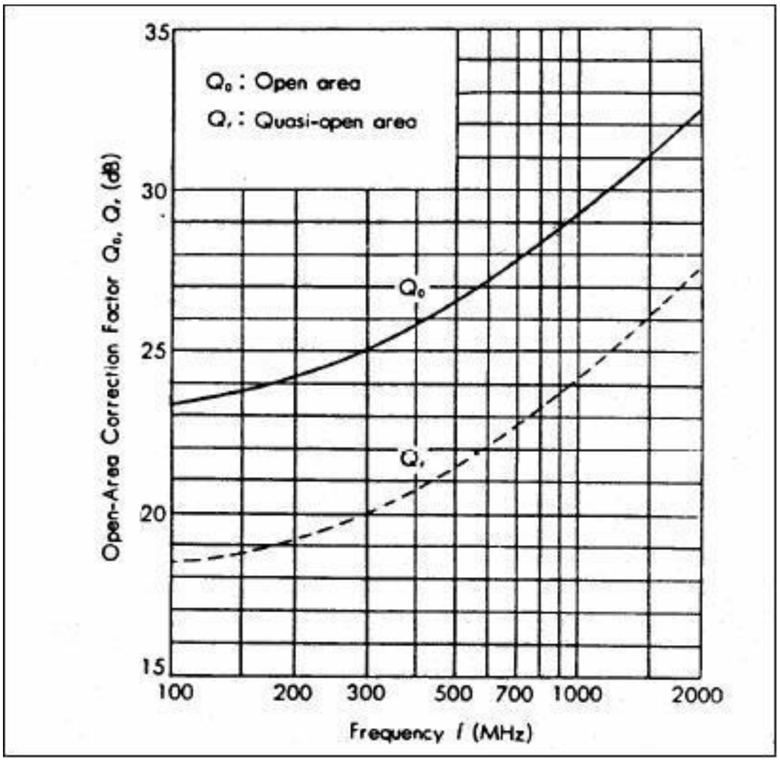

Figure 25 – Correction for open and nearly open areas (adapted from [18]).

$$K_{oa}(f)_{[dB]} = 4.78\,log^2(f_{[MHz]}) - 18.33\,log(f_{MHz}) + K \tag{3.17}$$

$$K_{qo}(f)_{[dB]} = K_{oa}(f)_{[dB]} - 5 \tag{3.18}$$

where, K ranges from 35.94 (rural) and 40.94 (deserts).

Naturally, the field intensity at the reception will increase as the density decreases buildings and obstacles.

3.3.2 Network capacity

In the most typical scenario, meters have transmission period spread throughout the day. These transmissions periods can be seen as a random variable uniformly distributed over 24 hours.

Communication takes place according to the following rules: first transmission of each meter is made at random time within the day, the next, with periodicity T, are determined using the de-synchronization system implemented by the standard. Sometimes, due to maintenance or control reasons, receiver may need to transmit some information to meters. In this case a bidirectional exchange of data may occur. For sake of simplicity, collisions do not require retransmissions. The main aspect that influences collision probability is the number of meter in the coverage area of each concentrator. The collisions are mostly related to the presence of many synchronous messages (due to lack of media access methods).

The transmission time of each frame is also considered important. This time, allows check how many counters may be connected to the network and how many counts are possible to realize in 24h. It is possible to estimate the transmission period for the different WM-Bus data rates according to the equation (3.19).

$$T_{TX} = \frac{8 \cdot Packet\_Length[bits]}{Data\_Rate\ [kbps]} \tag{3.19}$$

To calculate the transmission time, the packages are considered with a size of 256bytes. The WM-Bus protocol prescribes several data rates for the N mode. The N2g mode has a data rate of 38,4kbps, so the transmission time is 53,3ms.

The energy requirements exhibited by the protocol are evaluated for a single communication cycle, on a bidirectional link, at an operating frequency of 169MHz. All transmissions are performed at a maximum power of 27dBm (500mW), this requisite is defined by Community Decisions to stations exempt from licensing [15].

3.4 Planning WM-Bus System

After meeting all the specifications of WM-Bus system, it is necessary to plan a network. Initially, in the coverage planning is necessary to set the stage for deciding the amount and location of receivers, aiming to ensure the best possible coverage.

The main result of network planning is an estimate of the necessary equipment to meet the following requirements:

- Availability;
- Coverage;
- Quality.

Tests will be conducted on three types of scenarios, Urban, Suburban and Rural.

3.4.1 Urban Environment

The urban environment considered is the county of Lisbon (Figure 26), an area of 100 km^2, whose morphology of the terrain requires careful consideration with regard to the location of Collectors, because it is an area with great concentration of large buildings (Table 11).

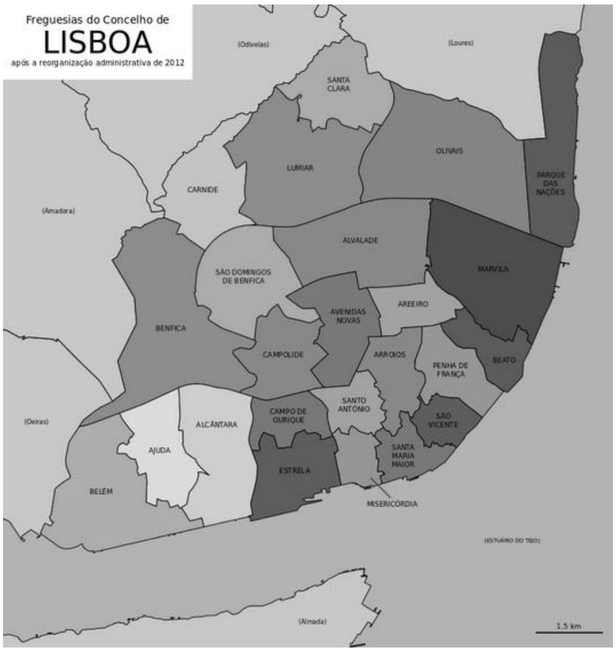

Figure 26 – Municipality of Lisbon (adapted from [20]).

Table 11 – Average number of classic family households, per km^2 (adapted from [21]).

	Average number of households by km^2	
Years	**2011**	**2013**
Lisbon	3800,6	3236,9

For the radius of coverage and propagation losses were made theoretical calculations of link budget were made with Excel, using the equations mentioned in Chapter 3.3. The results are presented in

Table 14, Table 15 and Table 16.

Table 12 – Parameters of the WM-Bus.

Model Parameters	
Frequency [MHz]	169,41
Collector Antenna Height [m]	30
Endpoint Antenna Height [m]	1

Table 13 – Path Loss Calculation – urban environment.

Path Loss Calculation	
Tx Power [dBm]	27
Collector Tx Antenna Gain [dBi]	2
EIRP [dBm]	**29**
Meter Sensitivity (Msens) [dBm]	-120
Endpoint Rx Antenna Gain [dBi]	2
Shadowing Margin [dB]	2
Rayleigh Fading Margin (RF Margin) [dB]	2
Log-Normal Fading (σ_{LNF}) [dB]	12
Building Penetration Loss (BPL) [dB]	18
Penetration Loss [dB]	35,4
Required sensitivity (Sdesign) [dBm]	**-48,60**
Propagation Loss (Lp) [dB]	**77,60**

Table 14 – Cell Radius – urban environment.

Cell radius using Okumura-Hata	
hCollector [m]	30 – 200
hEndpoint [m]	1 – 10
R [km]	0,135
Cell area [km^2]	0,057

To an urban environment we conclude that the coverage radius is 135m.

3236,9 houses per km^2 [21] were accounted in Lisbon in 2013 (Table 11). As the city of Lisbon is considered an urban environment, with high density of buildings/homes, and where the coverage radius is around 135m, Lisbon will require 1752 collectors.

3.4.2 Suburban Environment

For the suburban environment is considered the locality Marvila (outside the center of Lisboa) where there are not large concentration of very large buildings. There are some cross streets between buildings, but not in great amount as in the urban environment.

We calculated the link budget, through the formulas shown in the previous chapter for this environment and the results are presented in the Table 15.

Table 15 – Cell Radius – suburban environment.

Cell radius using Okumura-Hata	
hCollector [m]	30 – 200
hEndpoint [m]	1 – 10
R [km]	0,206
km^2	0,134

For a suburban setting we conclude that the coverage radius is 206 meters, approximately.

3.4.3 Rural Environment

The Bunheiro area of the parish of Murtosa municipality is selected to be considered as a rural environment (Figure 27). It is a very flat area and has an area of 24,60km^2, consisting of 36,6 houses per km^2 [21].

Figure 27 – Municipality of Murtosa (adapted from [20]).

To find the radius of coverage and the propagation losses the same link budget theoretical calculations were applied. The results are presented in the Table 16.

Table 16 – Ray Cell – rural environment.

Ray Cell: Okumura-Hata	
hCollector [m]	30 – 200
hEndpoint [m]	1 – 10
R [km]	0,635
km^2	1,27

For a rural setting we conclude that the coverage radius is 635 meters.

In Bunheiro, which is considered a rural environment, with little vegetation and few obstacles, 20 collectors are necessary.

Chapter 4

Planning Network Scenarios and Results

In this section, the equipment used is described and planning is applied for various scenarios of the different environments. Measurements in a real environment are carried in order to compare the results with the propagation model, used for this system.

4.1 The WM-Bus module

AXSEM produces equipment to perform telemetry of the several services such: gas, electricity, water and heat. It released a DVK-2 Kit (Figure 28), to perform measurements.

The DVK-2 is AXSEM's second-generation development kit for the designer starting out with AXSEM's family of high performance RF devices and microcontrollers. The system includes all required hardware and software to develop products in shortest times. This module was chosen as the most suitable solution in terms of quality, low cost and support community for the RF range tests and the basic RF communication.

Figure 28 – Development Kit DVK-2.

4.2 Overview and hardware

The aforementioned kit uses the AX8052F100 ultra-low-power microcontroller for RF applications. It allows developers to design, program and evaluate their applications using AXSEM's radio chips and microcontrollers under real world conditions. A range of RF-modules with different AXSEM RF ICs for various RF carrier frequencies are available as add-ons.

The hardware is designed to demonstrate the features of the AX8052F100 AXSEM RF-ICs. The ultra-low-power microcontroller can be used in all operating modes including low clock speeds and sleep modes. A pair of main boards together with an RF add-on is the perfect base to evaluate and develop RF systems. All RF-modules are matched to 50 Ohm and are equipped with SMA connectors that can either be used with antennas or connected to laboratory equipment.

The DVK-2 kit comes with:

- 2 main boards;
- 2 antennas;
- Debug adapter;
- Debug cable;
- USB cable;
- Batteries.

4.2.1 The DVK-2 Mainboard

The DVK-2 mainboard (Figure 29) is the core of the DVK-2 development system. It uses an AX8052F100 versatile ultra-low-power micro-controller. The mainboard is designed to evaluate AXSEM radio IC as well as being a platform for code development and testing.

Development Board Features:

- AX8052F100 microcontroller;
- RF-SPI Interface to AXSEM RF Modules;
- 32 kHz XTAL;
- 2 LED;
- 2x16 LCD display;

- RS-232 interface;
- Port break-out;
- AXSEM debug link RJ45 connector;
- Battery or debug link powered.

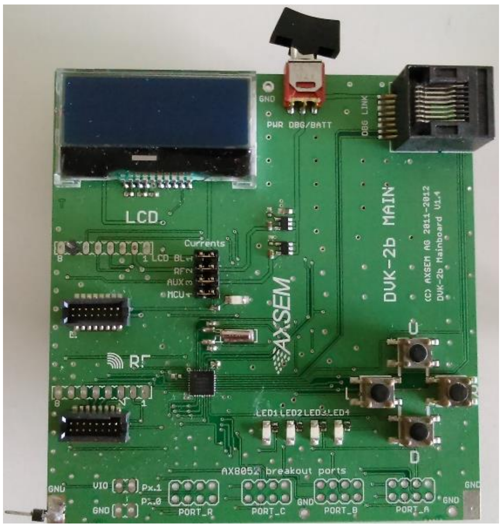

Figure 29 – AX8052F100 microcontroller.

The following RF-ICs modules (Figure 30) are available to plug onto the DVK-2 main boards:

- AX5051 general purpose transceiver modules for 868/915MHz: Unsurpassed wide band performance;
- AX5031 general purpose transmitter modules for 868/915MHz: Data transmission for wide and narrow band applications;
- AX5043 lowest power radio transceiver modules for 169.433 and 868/915MHz: -126dBm @ 9.5mA.

Figure 30 - AX5043 RF-ICs modules.

4.2.2 The AX8052F100 Microcontroller

The AX8052F100 is an ultra-low power microcontroller. It is optimized for use in battery powered applications together with RF ICs. The AX8052F100 offers high integration with attractive peripheral blocks, small footprint, easy communication with RF ICs, flexibility and ultra-low power consumption.

The AX8052F100 microcontroller core executes the industry standard 8052 instruction set. Unlike the original 8052, many instructions are executed in a single cycle. The system clock and thus the instruction rate can be programmed freely from DC to 20MHz.

The system clock that clocks the microcontroller, as well as peripheral clocks, can be selected from one of the following clock sources: the crystal oscillator, an internal high speed 20MHz oscillator, an internal low speed 640Hz/10kHz oscillator, or the low frequency crystal oscillator. Pre-scalers offer additional flexibility with their programmable divide by a power of two capabilities. To improve the accuracy of the internal oscillators, both oscillators may be slaved to the crystal oscillator.

AX8052F100 can be operated from a 1.8 to 3.6V power supply over a temperature range of -40º to 85º C. The AX8052F100 features make it an ideal interface for integration into various battery powered SRD solutions such as ticketing or as transceiver for telemetric applications e.g. in sensors.

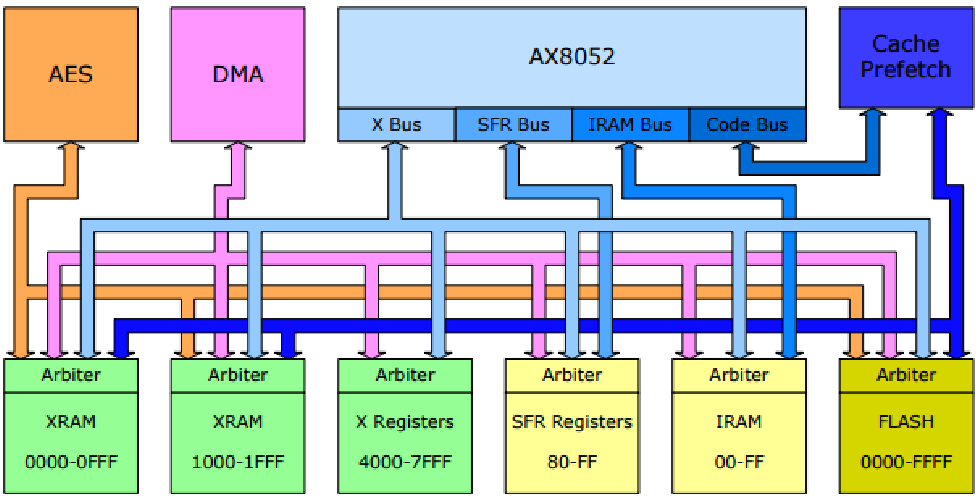

Figure 31 – AX8052 Memory Architecture (adapted from [22]).

The AX8052 Microcontroller features the highest bandwidth memory architecture of its class. Figure 31 shows the memory architecture. Three bus masters may initiate bus cycles:

- The AX8052 Microcontroller Core.
- The Direct Memory Access (DMA) Engine.
- The Advanced Encryption Standard (AES) Engine.

Bus targets include:

- Two individual 4 Kbytes RAM blocks located in X address space, which can be simultaneously accessed and individually shut down or retained during sleep mode.
- A 256 Byte RAM located in internal address space, which is always retained during sleep mode.
- A 64 Kbytes FLASH memory located in code space.
- Special Function Registers (SFR) located in internal address space accessible using direct address mode instructions.
- Additional Registers located in X address space (X Registers).

4.2.3 The AXSEM RF Modules

The RF-ICs module used to connect the DVK-2 main boards is the AX5043 narrow band high performance line modules

The AX5043 is a true single chip, narrow-band, ultra-low-power ASK and FSK RF transceiver for the 27MHz to 1050MHz frequency bands. It offers the unique combination of ultra-low power consumption for transmit and receive operation combined with highest sensitivity and high selectivity. A link budget of 143dB at 1kbps is achieved, if the built-in forward error correction (FEC) is used this can be extended to 146dB without extra external components. The AX5043 works perfectly down to 1kbps in a 6.25kHz channel. Though a TCXO is recommended for such operation, the AX5043 can also be operated with a normal XTAL if the necessary precautions are taken into account.

An integrated voltage regulation system allows the direct use of batteries and short start-up times enable time- and energy-efficient protocols. Transmit power and receive characteristics do not change over the supply voltage range of 1.8 to 3.6V. This makes the AX5043 ideal for battery powered portable applications. AX5043 features a lowest power wake-up clock and timer, which typically cousme 500nA, allowing it to autonomously handle wake-on-radio cycling.

The AX5043 supports FSK, MSK, 4-FSK, GFSK, GMSK, AFSK and ASK modulations. In transmit mode all modulations are shaped. For FSK gaussian filters with BT=0.3 or BT=0.5 are available to meet the most stringent regulatory requirements. Power ramping can be configured without restrictions. Maximum output power level is 16 dBm. The configurable packet engine supports a wide range of packet formats that are handled without microcontroller intervention.

The AX5043 has two main antenna interface modes:

1. Both RX and TX use differential pins ANTP and ANTN. RX/TX switching is handled internally. This mode is recommended for highest output powers, highest sensitivities and for direct connection to dipole antennas.
2. RX uses the differential antenna pins ANTP and ANTN. TX uses the single ended antenna pin ANTP1. RX/TX switching is handled externally. This can be done either with an external RX/TX switch or with a direct tie configuration. This mode is recommended for low output powers at high efficiency and for usage with external power amplifiers.

4.2.4 The AXDBG debug

The AXDBG debug adapter (Figure 32) is the interface between the PC and the mainboards. It can be used for programming and debugging the AX8052F1xx family of micro-controllers. It interfaces on the computer side with low level drivers and the AXSDB software interface, which is then used by other AXSEM software products. The AXSDB can also be used in mass production with the scriptable AXSDB software.

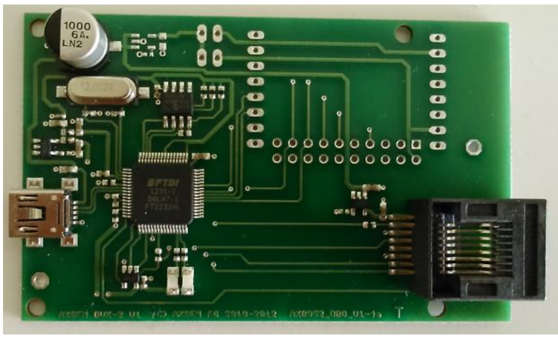

Figure 32 – The AXDBG debug adapter.

4.2.5 The Batteries

The DVK-2 mainboard is powered by 3 AA batteries.

Three AA batteries can be inserted on the bottom side of the DVK-2 mainboard. The polarity is indicated on the picture below. The power switch toggles between battery powered and debug-link powered operation. There is no OFF position if batteries are inserted and the debug-link is connected.

One radio module can be connected to the main board. The DVK-2 modules have to be connected to the main board with the SMA connector facing outside.

4.2.6 The Antennas

Different types of antennas can be used with the AXSEM radio modules. The kits come without antenna, nevertheless any 50ohm antenna, designed for a frequency matching the radio module and being equipped with a male SMA connector can be used. Be aware that antenna performance can change significantly among different vender.

4.2.7 The Software

To program the module according to the application, the DVK-2 comes with a productivity enhancing IDE and C-compiler. The AXCode::Blocks integrated development environment (IDE) is a complete tool suite that supports development and debugging of C and assembler code for AXSEM microcontrollers. Its intuitive GUI provides an environment that accelerates the development cycle. The tabbed interface with code highlighting and folding helps to keep overview, while code completion, smart indent and a class browser help to speed-up code generation.

The AX-RadioLab, AXGen2-RadioLab and AX-MicroLab code generators create fully functional sample code for a variety of applications. While the AX-RadioLab code generators focus on typical Radio Applications, AX-MicroLab creates typical microcontroller application examples.

In this work the AX-RadioLab for AX5043, was used. This is a Windows GUI program to create C-code applications for AXSEM's AX8052 microcontroller and AX5043 lowest power radios. With the AXSEM development system AX8052IDE the code can be directly compiled and downloaded to the AXSEM development kits DVK-2.

4.3 Measurements Sites

Measurements were carried out in different environments in order to assess the validity of the propagation model described in Chapter 3.

The different environments are characterized as follows:

- A rural environment, where there is absence of obstacles, that is an area open in a 300 of 400m radius.
- A suburban environment, where there are some obstacles, not too dense, several buildings with a maximum of 7 floors. In this environment the emitter will have two locations: inside the building, near the entrance and outside the building, on the building's terrace.
- A urban environment, where there is a high density of buildings, each with more than 7 floors.

4.3.1 Rural Environment

Measurements in rural environment were made in the area as shown in Figure 33. This environment is characterized by being quite flat, with little or almost no obstacles and little vegetation which allows very favorable signal propagation. Several measurements were made, around the area where the meter was installed. Below we can see some of the different positions measured.

In Figure 33, one can see that the measurements are carried out in open spaces without any obstacle.

At these points the signal are presented without any failure in receiving data. The signal quality is quite favorable because there are no obstacles between the meter and the receiver that may cause undesired attenuation. All the messages (data) sent were successfully delivered. As it was found that in point 5, due to the presence of some buildings there are few data loss.

Figure 33 – Location of measurement points in rural environment.

In Table 17, one presents results for the rural scenario.

Table 17 – Result tables in a rural environment.

	Point 1	Point 2	Point 4	Point 3	Point 5
Distance [m]	97	246	253	303	647
RSSI [dBm]	-94	-108	-115	-96	-110
Messages Delivered / Total	100/100	100/100	96/100	100/100	97/100

As we see in Table 17, there are data losses at Point 4 and Point 5. At Point 4, at a distance of 253m, there is a data loss due to the obstacle's density between the receiver and the meter, while at Point 5, the reason that leads to data loss is the increase of the distance between the receiver and the meter. The increase of the distance and the density of obstacles are important factors in signal reception quality.

4.3.2 Suburban Environment

In the suburban environment are considered buildings of 7 floors at most. The measurements were performed at the various floors of a building. The collector is installed on the terrace of this building. However also they were made measurements in neighboring buildings with the meter installed on the first floor of the neighboring building. These measurements allow determining the maximum range for good reception data when the signal has to pass through a set of obstacles (in this case, walls).

First measurements were made inside the building at different floors. In this case, there are no problems of communication, there is no packet loss and signal strength is quite satisfactory. Table 18 shows the results for the suburban scenario.

Table 18 – Result tables in a suburban environment, inside the building.

Floors	7	6	5	4	3	2	1	0
RSSI [dBm]	-59	-67	-74	-80	-82	-80	-83	-85
Messages Delivered / Total	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100

These measures, we find that between the building's floors, there is no problem in signal propagation, this means that there is no loss of data between the receiver and the meter. All 100 messages were successfully delivered.

The following measurements were realized in neighboring buildings (1st floor) at larger distances relative to the first measurements. Figure 34 shows the locations of measurements.

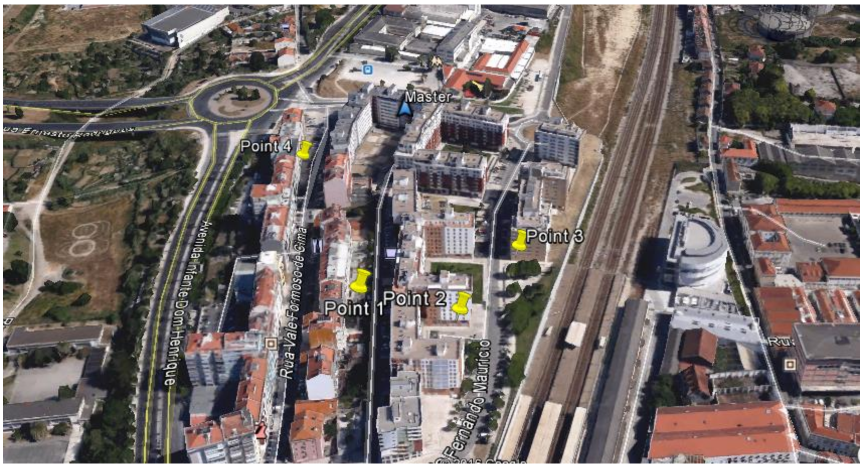

Figure 34 – Location of measurement points in suburban environment.

In a suburban environment there is a higher concentration of buildings and fewer empty spaces relative to the rural environment. With this scenario, it is verified data loss, signal quality and distance (cell radius) decreases relative to the rural environment.

Table 19 presents results in neighboring buildings.

Table 19 – Result tables in a suburban environment, outside the building.

	Point 4	Point 3	Point 1	Point 2
Distance [m]	80	161	181	220
RSSI [dBm]	-96	-110	-85	-118
Messages Delivered / Total	100/100	97/100	100/100	70/100

In the second measurement (Point 2) there is a higher data loss. The receiver and the meter are at distance of 220m and between them there are several buildings. In addition to distance, the existence of obstacles degrades the signal quality and failures occur in the data reception.

In this environment, to obtain a good reception the maximum distance decreases relatively to rural environment.

4.3.3 Urban Environment

In the urban environment, buildings with more than 8 floors, measurements are carried out on building’s exterior and at the first floor (of the building with the receiver on top). Figure 35 shows the locations of measurements.

Figure 35 – Location of measurement points in urban environment.

The receiver is located on the building top (11 floors) and measurements were performed surrounding buildings (at first floor). In Point 6 (located at ground level) was used to check the signal difference from a smaller building (building suburban environment).

It is noted that in an urban environment there is a higher packet loss in similar distances with suburban, and the signal starts to get weaker as it crosses a large number of obstacles, in this case more buildings.

In Table 20, one presents results for the urban scenario.

Table 20 – Result tables in urban environment, outside the building.

	Point 6	Point 3	Point 2	Point 4	Point 5	Point 1
Distance [m]	30	80	137	162	175	185
RSSI [dBm]	-113	-112	-118	-122	-122	-110
Messages Delivered / Total	97/100	91/100	71/100	64/100	89/100	91/100

In the urban environment, it the existence of high buildings dominates propagation, thus for a good data reception, the distance between the receiver and the meter can not exceed 150m, approximately. In general, one of the major problems in urban areas occurs because there are many obstacles (very high building), with no line-of-sight between the receiver and the meter. Thus, the signal quality decreases because the propagation is mainly due to scattering of the signal caused by the surfaces of buildings and the diffraction around these.

In Figure 36, it can be noted, an acceptable approximation, of the Path Loss for the different distances in different environments.

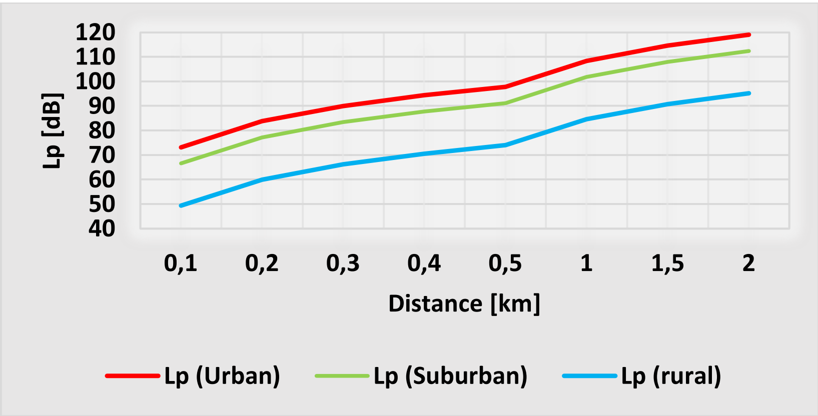

Figure 36 – Path Loss for the different scenarios.

4.4 Comparison of Results

The propagation of radio waves in urban environments is strongly influenced by environmental nature, in particular the size and amount of existing buildings. Studies on mobile radio waves propagation, often applies on environmentally qualitative description using terms such as urban, suburban and rural areas.

Urban areas are generally defined by dominated high-rise blocks and commercial buildings, and suburban areas are defined by home residences, parks and gardens. The term rural come to define areas with little construction and lots of greenery.

In Table 21 we can compare the calculated results of the maximum distance (cell radius) using Okumura model and the measurements made in different environment previous described.

Table 21 – Comparative table of the cell radius between the model and the measures.

Model \ Environment	Urban	Suburban	Rural
Okumura-Hata	135m	206m	635m
Measures	160m	220m	650m

Through the Table 21 we can analyze the maximum distance is very close to the acceptable range for a successful data reception. The model values correspond approximately to the measured in the field. These data may vary depending the type of materials of obstacles that exist in between the receiver and the meter.

Chapter 5

Conclusions

In this section, describing the conclusions, problems found and future work.

5.1 Major Findings

This work investigated the suitability of the WM-Bus protocol for possible adoption, by evaluating its transmission performance in different modes, through measurements and theoretical calculations.

The major goal of the study was to identify whether the WM-Bus as specified within the norm specifications.

WM-Bus mode N (169MHz) seems to guarantee adequate performance in terms of range when applied to a single metering service with low data rate requirements.

The WM-Bus protocol at 169MHz seems able to ensure adequate transmission capabilities, in different environments, by providing a coverage range in the order of hundreds of meters joint a quite low sensitivity of the receiver.

For this work we chose the equipment ASWEN because it has a lower sensitivity which leads us that it has a greater range, and a low current consumption.

In measurements carried out it appears that the maximum distance approaching almost theoretical data. It is found that in an urban and suburban environment distance is not more than 200m while a rural environment we can see that the maximum distance coverage increases to almost 700m. The results of the measurements made on the field show a satisfactory agreement with the classical model of prediction used. The maximum distances calculated by Okumura-Hata model, meet the acceptable values from the measurements performed in different environments.

It can be concluded the empirical Okumura-Hata model can be apply to predict the propagation in the analyzed environments when used WM-BUS protocol mode N.

5.2 Future Work

There is much work that needs to be performed in this field. One of the important issues is to make a comparative study between the various operating modes. It would be important to compare the performance of the different modes used up to frequencies of 868MHz, in order to check the advantages and disadvantages of each.

It is possible the integration of several meters, however this integration would have unwanted effects, such as consumption of the devices, ie the time the batteries would be shorter due to increased transmission time, then there would need to change the batteries on a lower space of time. However, an urban environment, it would be ideal to implement a device that made the reading of all meters (electricity, water, gas and heat) in a single device. Reduce the number of devices at the entrance of each house. This is to avoid, in a ten floors building with two housing per floor, a counter for each service should be scary.

I think that this implementation would be very useful in times of today, since in times of economic crisis, we do not like to pay more than we consume and with this telemetry service we would have counts at any time avoiding expenses for estimates.

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