ROBOTS IN ASSISTED LIVING ENVIRONMENTS

UNOBTRUSIVE, EFFICIENT, RELIABLE AND MODULAR SOLUTIONS FOR INDEPENDENT AGEING

Research Innovation Action

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Abstract

Report document pertaining to the first phase of work conducted in the context of T3.3 regarding methods, designs, algorithms and techniques targeting network robustness and efficiency.

History and Contributors

Ver	Date	Description	Contributors
01	1 Jun 2015	First draft, establishing document structure and work allocation.	TWG
02	8 Jun 2015	First contribution on Bridging between smart home and robot domain	S&C
03	10 Jun 2015	Design and on-going development description on a novel heterogeneous technologies supporting GW	TWG
04	16 Jun 2015	Additional contribution on Bridging between smart home and robot domain	S&C
05	18 Jun 2015	Contribution on prominent low power communication performance evaluation	TWG, AVN
06	21 Jun 2015	Design approach towards BLE mesh support	TWG, AVN
07	6 Jul 2016	Internal Review	RUB
08	8 Jul 2016	Addressing internal review comments	TWG, AVN, S&C
Fin	11 Jul 2016	Final document preparation and submission	NCSR-D, TWG

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1 INTRODUCTION

1.1 Purpose and Scope

This deliverable is the first report describing the progress in Task 3.3 the main objective of which is to explore technologies, develop methods and design architectures pertaining to the network robustness and communication infrastructure efficiency upon which RADIO services can be based.

This deliverable aims to present different approaches and aspects explored by the consortium in order to strengthen network robustness and increase its efficiency.

1.2 Approach

The RADIO network infrastructure comprises various and diverse entities that need to collaborate so as to support the development of required services and wireless data transfer requirements. In that respect, different prominent ultra-low power IoT wireless communication technologies are explored and evaluated highlighting respective characteristics pertaining to robustness and network efficiency. Approaches are designed and developed aiming towards novel features such as multi-hop communication capabilities to technologies currently not supported also focusing on enhanced network robustness and efficiency. Furthermore, as it is clearly highlighted in the context of RADIO, the Home Assistive Robot comprises probably the most important cornerstone of the whole RADIO platform. Therefore, bridging techniques enabling robust and efficient interaction between the RADIO home automation environment and the Robot comprise a critical part of this deliverable. Finally, the gateway also comprises an entity of particular importance effectively connecting all other entities (i.e. the Home automation environment, the Robot, the IoT platform) thus drastically affecting communication robustness and efficiency. In that respect novel architecture designs and implementations are explored and presented aiming to offer efficient and seamless support of heterogeneous Wireless Sensor Network communication technologies, back-end communication technologies as well as offering advanced processing, storage and schedule features.

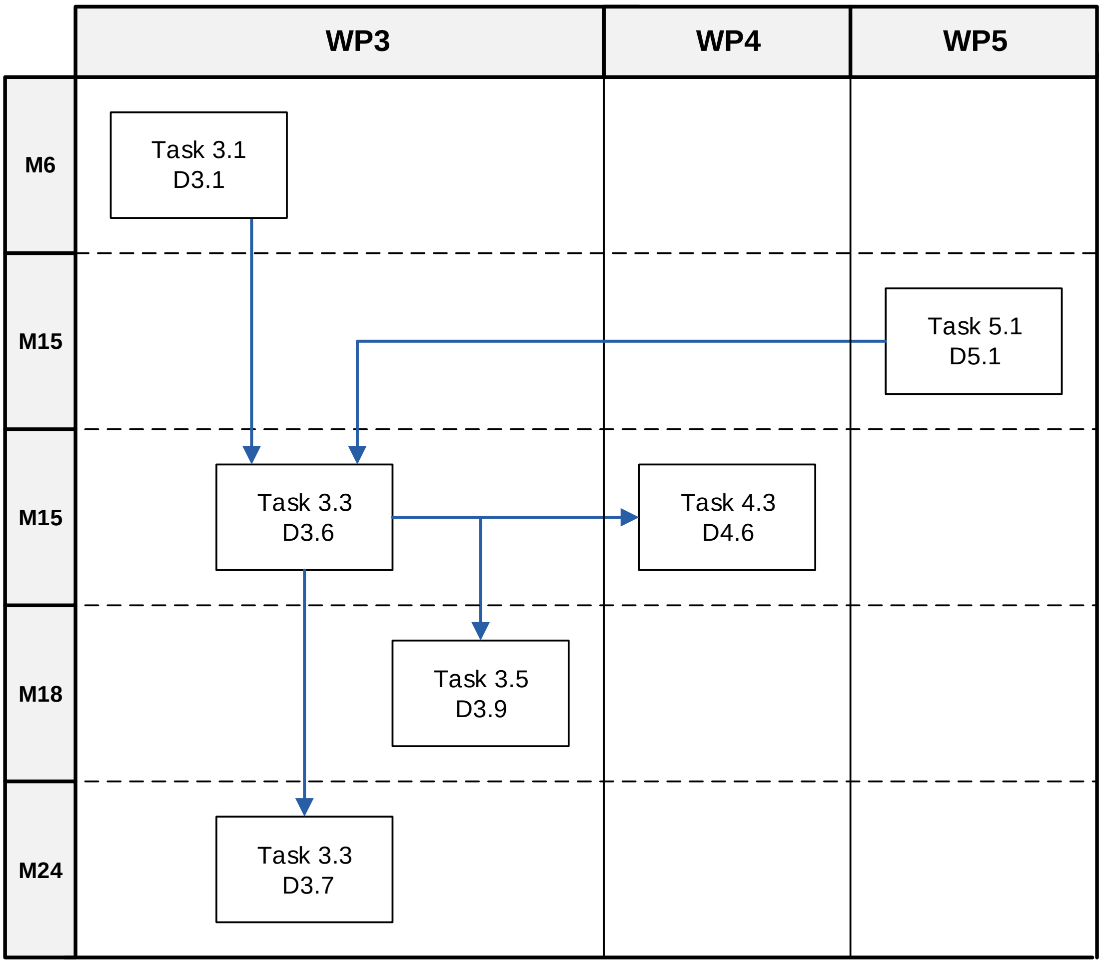

Figure 1: Relation to other Work Packages and Deliverables

1.3 Relation to other Work Packages and Deliverables

This document is the first of two related deliverables: this deliverable (D3.6) and the final version of the *network robustness and efficiency methods* (D3.7).

The methods in this deliverable follow the *Conceptual architecture for sensing methods and sensor data sharing I* (D3.1) to ensure interoperability with RADIO components and to be informed of critical characteristics of the RADIO communication network architecture.

The *communication*, *processing* and *security efficiency methods* described in this deliverable are relevant to the robot prototype (D4.6) and the mechanisms and protocols for the communication between the on-board components and the rest of the RADIO Home.

The technologies, methods, and designs in this deliverable are used in the integrated data analysis system (D3.9).

2 PERFORMANCE EVALUATION OF LOW POWER WIRELESS COMMUNICATION TECHNOLOGIES

Nowadays a plethora of short range, ultra-low power wireless communication technologies are available, all aiming to meet the requirements posed by home automation monitoring and control, event detection and even data streaming of relatively low bit rates. Therefore in the context of home automation in RADIO as well as transmission of events created by ADL algorithms a basic research has been undertaken aiming to evaluate the prominent examples of such technologies in a common set of scenarios so as to extract useful and practical conclusions with respect to the real requirements anticipated in RADIO scenarios. The set of technologies under evaluation comprise mature solutions integrated in wide range of commercial solutions targeting home automation application domain. The goal of this effort is mainly to extract and highlight respective pros and cons enabling the optimum selection of respective technology with respect to specific application scenario requirements both in the context of RADIO cases and beyond.

2.1.1 IEEE 802.15.4 Based Solutions

2.1.1.1 Introduction

Respective solutions comprise prominent candidates as they are utilized in several experimental and commercial scenarios. As the title implies, the communication capabilities are based on the IEEE 802.15.4 standard finalized by October 2003 [Part15.4]. Their popularity, gained throughout the years, is based on significant advantages when aiming towards very low power, low complexity, low price and low application demands characteristics.

At the physical layer, IEEE 802.15.4 offers three possible frequency ranges, although the most popular is the 2.4GHz ISM band where 16 channels can be utilized offering the highest bit rates equal to 250Kbps [Part15.4]. However, it is noted that at each particular time only one channel can be used, thus not being a multi-channel protocol.

Concerning the data transfer approaches, although the IEEE 802.15.4 defines approaches for both contention-less and contention based access schemes, the respective platforms implement and utilize only simple contention CSMA based approaches. Following such an approach, all nodes are peers (i.e. there is no coordinator) and sense the transmission medium for two reasons. On one hand if a node wants to transmit a packet, it senses the medium until it is identified as idle and then transmits the packet. On the other hand, from the receiver perspective, a node senses the transmission medium in order to identify a packet transmission towards itself.

Popular IEEE 802.15.4 based platforms considered in this evaluation effort include TelosB and MicaZ. TelosB comprises probably the most well know WSN platform upon which many projects have been based including medical oriented ones [CodeBlue], [Shimmer]. As expected it offers an IEEE 802.15.4 compatible RF transceiver which can deliver 250Kbps bitrate at the 2.4GHz frequency band. Processing is based on the (also widely utilized) 8MHz Texas Instrument MSP430 16bit microprocessor. Concerning memory capabilities, the developer is provided with 48KB program flash, 10KB data ram and a 1MB external flash. It is noted that, although now TelosB is available through Memsic Co [Memsic], there are other platforms which although under different brand name offer identical characteristics such as [CM5000] and [Shimmer]. Shimmer is also a very interesting case since it offers a very versatile environment. A wide range of medical sensors can therefore be utilized extensively in this evaluation effort. MicaZ also comprises a prominent platform used in various scenarios and offering analogous characteristics as TelosB. The main difference concerns the processing module, which is based on an Atmel ATmega128L for both the radio and processing tasks offering 128KB program and

512KB data memory, while TelosB motes are USB programmable and chargeable thus offering considerable higher usability compared to MicaZ where a separate programming module is required. It is noted that products exist claiming higher bitrates [radio_pulse] for specific applications. Higher data rates supported beyond the standard rates, comprise custom solutions offering limited features as far as software and network stack openness especially compared to the significantly more widely utilized, considering research objectives, platforms mentioned before. Therefore they do not represent adequate solution for this evaluation.

2.1.1.2 Performance Evaluation

Undertaken evaluation focused on a typical scenario concerning a star topology comprised by one aggregating base-station node and variable number of reporting nodes. Additionally, the packet size also comprises a potential critical factor affecting the amount of information that a single packet can convey and the time period in which a wireless transmission medium is captured by a single transmitter. Finally, the most important system level performance metrics concern the rate of data the wireless medium can accommodate pertaining to the realistic capacity of the network and the mean packet delay pertaining to the time constrained communication capabilities of the network.

The evaluation results and their analysis are separated in two subsections, focused on the two performance aspects in CC2420 radio, delay and throughput. The first analyzed aspect is delay. Measurements presented in Figure 2 consider scenarios with and without security provision with a stable packet payload of 8 Bytes. As result, the relative effect of critical network parameters can be identified.

Focusing on the depicted graphs varying the number of transmitters (1,2,4), it is easily extracted, that the number of competing nodes comprises the most significant factor in IEEE 802.15.4 networks. Specifically, when no competition is developed (1 node communicating), the network exhibits low delays (around 10msec and never super passing) in all considered cases. On the contrary, increasing the competing nodes results in a delay increment to 25msec as packet creation interval for 2 nodes and even 100msec for 4 nodes. The highest delay measured also increases considerably in the 4 competing scenario reaching 23msec.

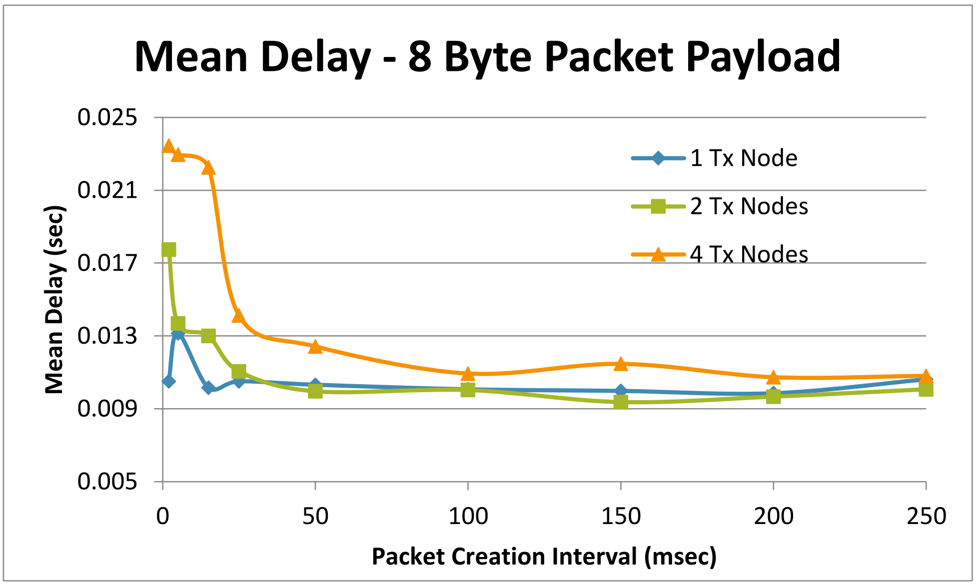

Figure 2 IEEE 802.15.4 Mean Delay Performance with regards to Tx Nodes

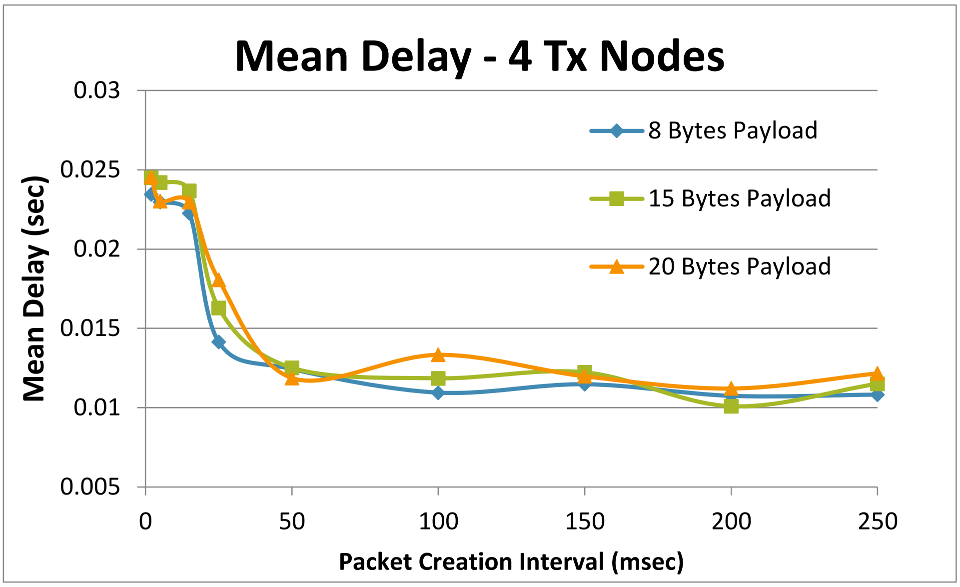

Figure 3: IEEE 802.15.4 Mean Delay Performance with regards to Packet Payloads

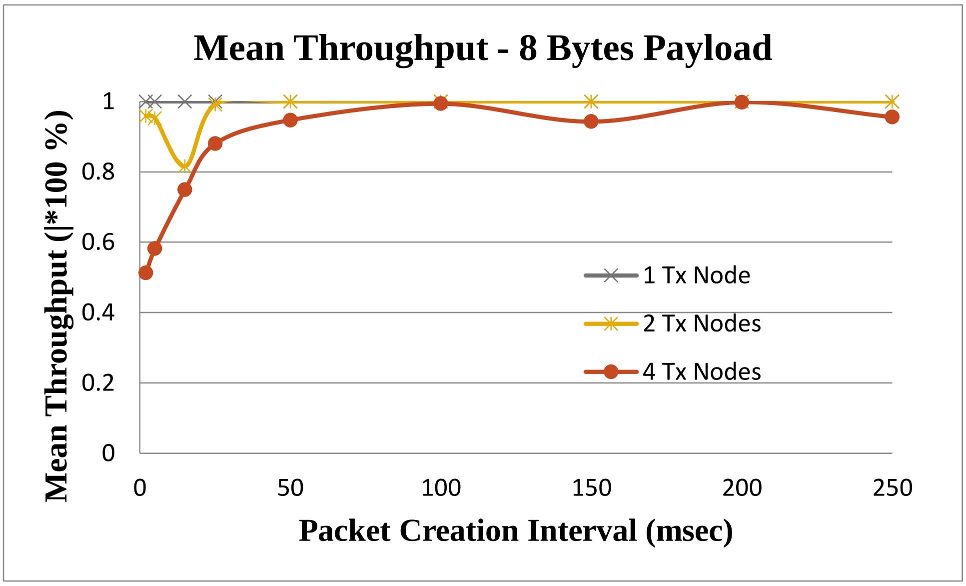

Figure 4: Mean Throughput of CC2420 Testbed wrt No Security

IEEE 802.15.4 offers significant flexibility and configurability as to the size of the packet defined by the user. Therefore, the next figure focuses on how network parameters and data payload affect the delay performance of the network in real CC2420 networks. In the following figures, the scenario represented is with 4 concurrent transmitting nodes and variable data payload size.

As extracted that different data payloads do not affect delay performance of the network when the competing nodes remain in relatively low but realistic numbers (i.e. 4 competing nodes) for typical scenarios. Therefore, in such cases using large packets is advocated in order to maximize the utilization of limited available bandwidth and if possible lower the required number of actual transmission for the same amount of data to be transmitted.

The second analyzed metric is throughput. As presented in the following figures, respective measurements concern the ratio of successfully received packets to the total number of packets transmitted. Figure 4, presents our measurements with a fixed packet payload of 8 Bytes.

Once again the number of competing nodes emerges as the most critical factor. With 1 competing node network we have 100% communication success. Increasing the competing nodes considered results in throughput degradation from 25msec packet creation interval for 2 nodes and even 100msec for 4 nodes. It is noted that when there are two competing nodes performance degradation does not always occurs since it is possible that the two nodes synchronize their transmissions (through CSMA MAC protocol) in such a way that packets are not transmitted at exactly the same time. Effectively this is a statistical phenomenon not accurately quantified. Thus what is shown in Figure 3 are essentially mean valued of numerous repeated experiments. This is not the case in 4 transmitting nodes where performance degradation is always recorded as clearly indicated by the linear graph. The most severe degradation observation concerns 4 competing nodes, and 2 msec packet creation interval, where mean throughput decreased to 51%. This result is quite discouraging for ARMOR related scenarios where multiple data flows will certainly coexist while transmitting in relatively high rates.

2.1.2 Bluetooth Based Solutions

2.1.2.1 Introduction

Bluetooth is a wireless radio specification designed to replace cables as the medium for data and voice signals between electronic devices. The specification is defined by the Bluetooth Special Interest Group (SIG) which is made up of over 1000 electronics manufacturers. Intended primarily for mobile devices, Bluetooth’s design places a high priority on small size, low power consumption and low costs. The Bluetooth specification seeks to simplify communication between electronic devices by automating the connection process.

Bluetooth radios operate in the unlicensed 2.4GHz Industrial, Scientific, and Medical application (ISM) frequency range. This frequency is already widely used by devices such as microwave ovens, baby monitors, cordless telephones, and 802.11b/g wireless networking devices. In order to avoid interference from these devices, Bluetooth uses a technology called spread spectrum frequency hopping. Spread spectrum frequency hopping changes the transmission frequency up to 1600 times per second across 79 different frequencies. As a result, interference on any one of those frequencies will only last a fraction of a second. This, coupled with the limited range of Bluetooth radio transmitters, results in a robust signal that is highly tolerant of other devices sharing the same frequency.

Bluetooth devices automatically attempt to communicate whenever one device comes within range of another. Bluetooth devices discover each other and initiate communication via inquiry and page transmissions.

Bluetooth devices have the ability to form ad hoc networks. The topology of these networks is both temporary and random. An ad hoc network of two or more Bluetooth devices is called a piconet. When two Bluetooth devices initiate a connection, they automatically determine if one device needs to control the other. Generally, the device that initiates the communication assumes the role of master and exercises certain controls over the other members of the piconet which are known as slaves. Upon establishing a piconet, the slave devices synchronize their frequency hopping sequence and system clock with that of the master in order to maintain their connection. A master device can have up to seven slaves. A slave in one piconet can also be the master in another, thus allowing piconets to overlap and interact forming what is known as a *scatternet*.

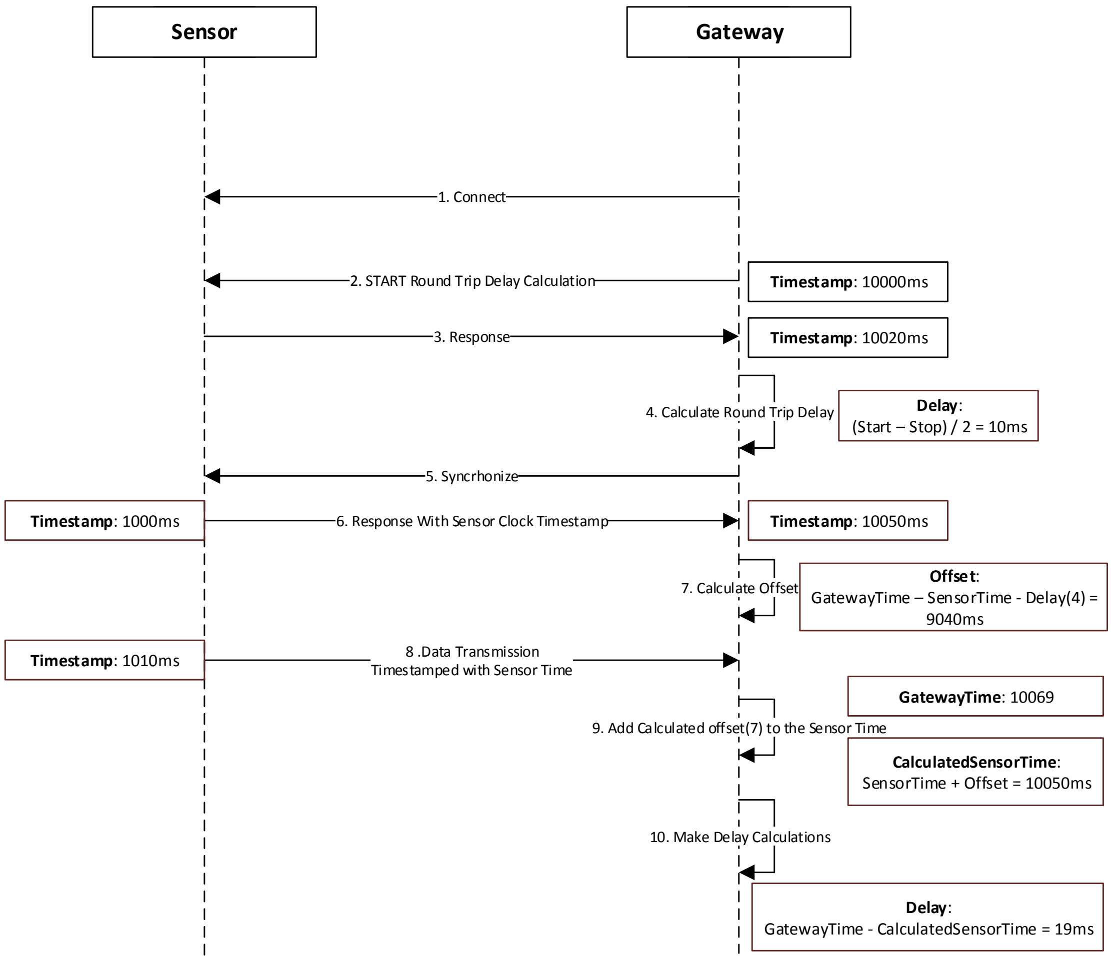

Figure 5 Clock offset calculation procedure for Bluetooth based measurements

Contrary to IEEE 802.15.4 based solutions where all relative platforms are characterized by analogous capabilities, the platforms in Bluetooth based solutions can vary significantly depending both on the version of the protocol supported and even more on the specific implementation's characteristics. Therefore, concerning data rates solutions covering a wide range from 300Kbps up to 1.5Mbps can be found. Indicative examples of relative solutions include Shimmer [Shimmer] and MoviSens [MoviSens] platforms. The former is utilized in the Roving Networks based Bluetooth modules [Roving2011].

2.1.2.2 Performance Evaluation

In order to evaluate *Bluetooth (BT)* communication performance, the Shimmer [Shimmer] platform was utilized offering a highly configurable environment and a standardized BT communication over the SPP (Serial Port Profile) service offering trouble-free compatibility with various BT receivers (both PC embedded and USB dongle). From the transmitter side, TinyOS based source code allowed us to configure the size of the payload and convey through that payload all required information to conduct the evaluation. On the transmitter side, an application has been developed allowing to easily conduct the association with the transmitter/s node/s and the parsing of data in order to make adequate calculations and extract respective measurements. In order to identify packet losses, each transmitter tags with an increasing counter each packet created. In this way the receiver is able to check the sequence of the packet counter tags and identify any packet loss.

A significant issue that we had to address is how to accurately evaluate the effect on delay performance when both the transmitter and receiver have a completely different notion of time. In that respect before data transmission commences, a specific packet exchange sequence has been designed and developed as depicted in Figure 5 enabling the calculation of the two clocks' offset thus enabling the accurate measuring of data packet delay. As depicted, after the sensor and the GW are connected the round trip delay is measured and the second exchange occurs (5 and 6 packets) so as to extract the clock offset. After this point, data transmission can commence and after each packet reception the offset is taken into consideration to counteract the clock difference.

Now moving on to the rest of the evaluation experiments, critical parameters considered are:

- Packet creation interval: 5-150msec
- Concurrent transmitters: 1,2,4,6 (7 being the maximum by BT requirements)
- Packet payload: 9, 20 Byte

Measurements Results

The first and of utmost importance observation extracted for respective measurements with respect to the document's objective concerns that in all scenarios there was a 100% success in packet transmission. It is shown that connection-oriented communication and FHSS transmission techniques offer significant advantages as far as communication robustness is concerned leading to no packet loss either with or without security provisions as well as while varying the packet payload. Such an observation emphatically advocates that the use of such technology is demanding application scenarios where highly sensitive data are handled.

Therefore, the evaluation results and their analysis focused on delay performance. In all graphs axis X indicates the inter-arrival time between consecutive packets in milliseconds. Y axis indicates the delay in milliseconds. Also "B" refers to the data payload and "Tr" refers to the number of nodes in the WSN. Figure 6 presents our measurements with varying packet payload.

It is easily extracted that the number of concurrent transmitting nodes on Bluetooth networks comprises the most significant factor affecting network delay performance. Specifically, when there is only one transmitting node the network exhibits very low delays, with a little differentiation even for quite stressed traffic workload conditions (i.e. 5msec packet creation interval) where the delay of successfully transmitted packets was approximately 20msec. These observations are extracted from both 9Byte and 20Byte packet payload scenarios.

What is more interesting is that even with a 15msec packet creation interval, configuration of the Bluetooth based network efficiently handled the created traffic from four competing nodes. This is depicted in Figure 6 when for the specific packet creation interval only a slight increase in packet delay is recorded. However, a quite emphatic delay deration is observed when a packet is created by the application layer every 5 sec. In this case and considering small packet size (i.e. 9Byte packet payload) delay more than doubles compared to 1 transmitter node scenarios reaching approximately 50msec. Furthermore it is in this case where packet payload size is highlighted as a critical factor. This is extracted from 20B, Tr6 graph where the mean delay spikes up to 190msec invalidating time constrained capabilities compared to all other graphs.

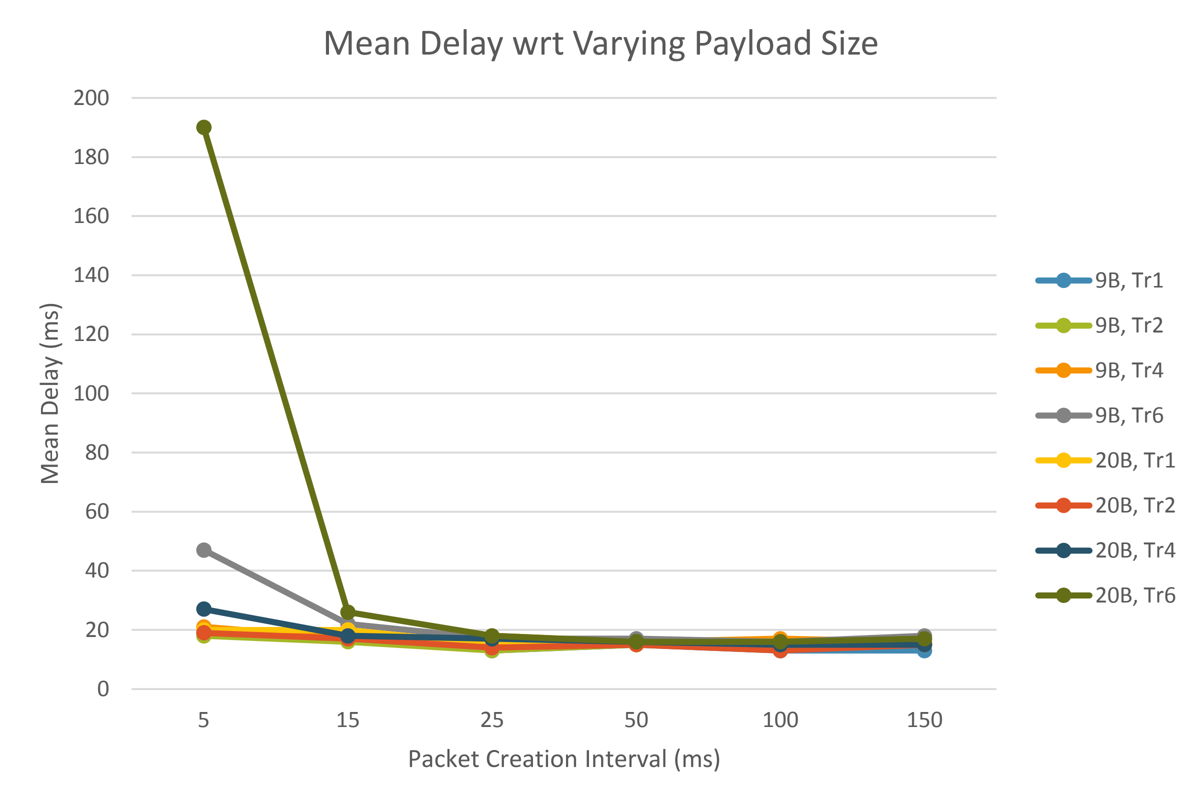

Figure 6: Mean Delay BT Performance

2.1.3 Bluetooth Low Energy Based Solutions

2.1.3.1 Introduction

Bluetooth Low Energy (BLE) represents a different technology from Classic Bluetooth (and in fact incompatible technology) being promoted by the Bluetooth Special Interest Group (SIG) and benefitting of the hugely successful Classic Bluetooth it shows significant dynamics compared to analogous technologies being incorporated for example in most mobile devices such as smart phones and tablets, in high percentage of laptops and even in the latest version 3 of the also hugely successful Raspberry Pi. Furthermore, as presented in D4.1 (and omitted here for reasons of repetition avoidance) it offers high degree of flexibility both concerning implementation approaches and communication approaches supporting different ways for nodes to communicate through different data structure profiles so as to best fit the application requirements. Both these aspects are critical for the RADIO objectives highlighting relative solutions as good candidates for RADIO purposes. Also, being a protocol in progress regarding various aspects it also offers the added value of allowing the members of the RADIO consortium to be members of the Bluetooth Special Interest Group (SIG) gain valuable insight on future features of the standards and if possible even proposal respective approaches. However, the main fundamental step is to actually evaluate respective solutions and realistically and objective verify that the performance offered is adequate for our goals.

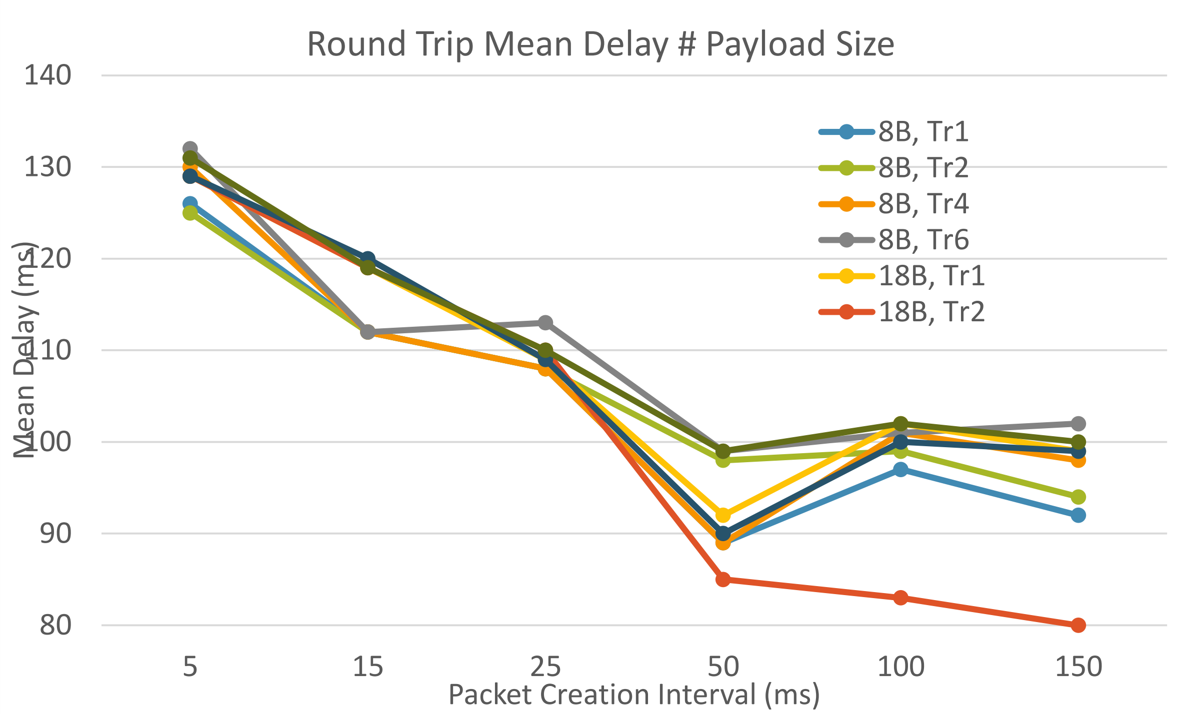

Figure 7: Mean Round Trip Delay BLE Performance

2.1.3.2 Performance Evaluation

In order to perform this fundamental performance evaluation we relied on the Sensor Tag [TI SensorTage] platform offered by Texas Instruments being a key player in BLE evolution. This platform comprises an ideal solution since it combines the best features from the commercial and research domain. With respect to the former aspect, relative platforms comprise very small nodes offering a wide range of sensors inside a robust case able to be used in real life scenarios. Concerning the research domain, relative nodes are programmable while the whole software stack is open source (offered by TI) allowing the development of custom solutions, possible extensions, enhancement and of course a way to test experimental ideas. In the context of aiming to test the communication capabilities under stressful scenarios, we created request-response sequences varying the request period while changing the number of nodes the gateway request data from. Specifically, considering as aggregation point a typical laptop equipped with a BLE USB dongle the number of nodes towards which requests are issued range from 1 to 6 while the request periods range from 150msec down to 5msec (effectively representing a very stressed communication scenario). Finally, for reasons of completeness two packet payloads were considered (i.e. 8 and 18 Bytes) so as to explore the respective effect. Each evaluation session lasted the required time so as the gateway is able to send 5000 request towards each node. Focusing on the application layer performance metrics recorded concerned the number of responses received (and most importantly those that were not received) and of course the round trip delay measured by the aggregation point (i.e. the equivalent of the RADIO gateway according to the overall system architecture).

The first and very important observation concerns the exhibited communication robustness since there was no packet loss recorded. Every request was successfully responded in all cases and by all BLE nodes considered. Secondly as depicted in Figure 7 this robust behavior is accompanied by a quite predictable delay performance and respective effect of considered parameters. Based on the recorded performance, it can be safely deduced that the request period is the critical parameter to be considered. For low traffic scenarios (i.e. 150msec request period) the recorded round trip is measured (for all graphs apart 18B, Tr2) in range of 90-100msec corresponding to unidirectional delay of 45-50msec independently to the number of nodes comprising the network or the packet payload considered. The second observation to be made concerns the request period equal to 25msec since it seems that these point on (i.e. for lower request periods corresponding the scenarios of increasing tress workload) a clearly leaner mean delay increase indicating a network moving towards congestion situations. However, even in the most stressed cases considered (clearly surpassing what is anticipated to be encountered in typical RADIO scenarios) the BLE network did not reach congestion since no packet loss and a measurable but relative low delay overhead is recorded. Specifically, as it can be observed maximum recorded round trip delay is in the range of 125-131msec roughly corresponding to a unidirectional delay of ~64msec easily covering any real time requirements posed by the RADIO application scenarios.

2.1.4 Summarization

Nowadays and most probably in the future there will be variety of different and diverse communication technologies claiming a part of the short range, ultra-low power, and wireless communication market. In this section a basic evaluation research is presented aiming to evaluate suitability with respect to the RADIO communication requirements and to reveal specific characteristics as well as pros and cons. Such insights are very important because we envision the RADIO platform as a continuously evolving system much beyond the RADIO project timeframe and in order to assure the extended lifetime of the developed framework it must be able to embrace and integrate current as well as new technologies. What is clear from studying the considered technologies both at literature level but most importantly by hands on experience and by putting them under a variety of tests is that each offers unique characteristics distinguishing each solution from the other and making each technology a better fit compared to the others considering different communication requirements both functional as well as non-functional. Therefore, we present a table of characteristics most relative to the RADIO communication aspects and we attempt to rank considered technologies.

	IEEE 802.15.4	**Bluetooth**	**BLE**
Low Power	Very good	Good	Excellent
Link Capacity	Medium	Very Good	Very Good
Affected by communication competition	Medium	Very Good	Very Good
Multi-hop communication support	Excellent	Medium	Very Good
Dynamic Topology	Excellent	Medium	Very Good
Time constrained performance adequate for RADIO	Yes	Yes	Yes
Low Cost	Very Good	Good	Excellent
Market Widespread	Medium	Excellent	Excellent

Table 1. Wireless Sensor Communication Technologies Ranking

From Table 1 it can be deduced the all the available solutions should be seen as competitive technologies but more as complementary solutions each on offering specific advantages to specific application scenarios and requirements. In that respect in RADIO aiming to offer highly efficient and robust communication solution and infrastructure, a critical goal will be to design and develop a novel Gateway component. The main focus is on enabling integration of all prominent heterogeneous technologies thus promoting cooperative communication and data transfer. Respective solutions will be presented in following section of this deliverable and a primary concern will be the seamless cooperation with commercial solutions offered in RADIO project.

3 Design of BLE Multi-Hop Communication Techniques

Bluetooth Low Energy (BLE) has attracted significant interest due to its inherent characteristics as briefly described in Chapter 2. The increased adoption of the BLE technologies in the IoT domain has enabled researchers, companies and the Bluetooth Special Interest Group (SIG) to explore the feasibility of mesh networking over BLE. Currently, enhancements focused on mesh networking are on the roadmap of all the BLE related vendors. BLE mesh support is expected to provide new capabilities and increase the IoT functionalities.

3.1 Current Trends

Dominant players in the market of low power wireless SoCs and BLE particularly, have already released their first efforts towards mesh enabled BLE networks. Since the standardization of a mesh mechanism for BLE has not been finalized yet, each company is working on its own version of mesh networking over Bluetooth.

CSR enables mesh networking through a proposed CSRmesh service layer [CSRmesh]. CSRmesh nodes receive advertisement messages and broadcast them to the surrounding devices with maintaining any routing table. Through this flooding mechanism, packets are propagated through the network of the BLE devices and thus, a simple ad-hoc mesh network is formed for the IoT application domain. The first large scale deployments of CSRmesh are applied in buildings with smart LED lighting fixtures and are controlled through Android and iOS devices. Details on CSRMesh are given later in the chapter where some primary performance evaluation is performed.

Nordic Semiconductors is another chipmaker that provides its version of mesh networking on its Bluetooth smart devices through the nRF OpenMesh framework [OpenMesh]. nRF OpenMesh is similar to the CSRmesh message rebroadcasting infrastructure. The message propagation is controlled by *Trickle*, a flood control algorithm for lossy low power networks [Levis, 2011].

Another popular vendor on the wireless communication SoCs, the Dialogue semiconductors, released the Smartbond DA14680 SoC family that is able to run the OpenThread [OpenThread] which is the open-source implementation of the Thread [Thread] networking protocol. Through the OpenThread Sandbox development kit, developers are able to establish mesh networking and evaluate the protocol stack’s performance.

Finally, Texas Instrument (TI) has released the prominent CC26XX SoC family that provides BLE connectivity. Though TI doesn’t distribute its SoC with a custom version of a mesh networking, developers can take advantage of the SoCs’ BLE 4.1 support and define their custom BLE mesh network with CC26XX using Advertising & Scanning

So far, each vendor provides its own approach on BLE mesh networking as already identified. In the meantime, the SIG has been focused on the standardization of mesh networking in order to include this standard into the Bluetooth specification. The main objective of the Bluetooth SIG through the respective working group is to allow mesh networking capability in the standard and add to the Bluetooth certified devices mesh networking functionality. As Bluetooth Smart sensors mainly target smart home applications, mesh networking aims to become an integral component in order to deliver Bluetooth-enabled smart locks, lights, Heating, Ventilation, and Air Conditioning (HVAC) systems, and cooperation among appliances.

The *Bluetooth Smart Mesh Working Group*, which is involved in the respective project, is supported voluntarily by over eighty member companies from a broad spectrum of industries, including automotive, mobile phone/mobility, industrial automation, home automation, consumer electronics, and computing. The Smart Mesh Working Group expects to have the specification ready in 2016.

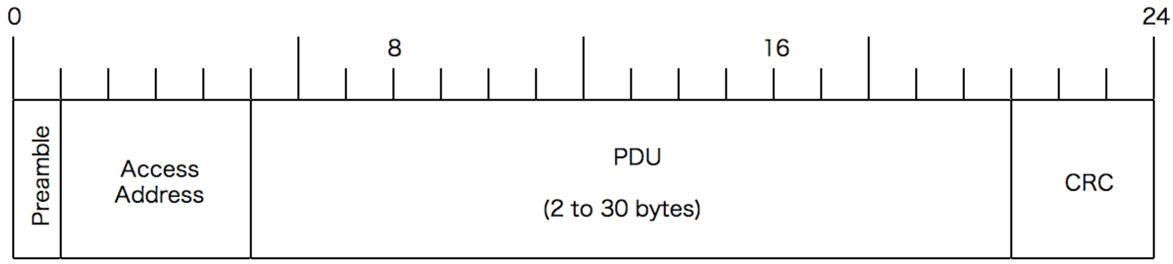

Figure 8: Advertisement/Scan Response packets' structure

3.2 RADIO Solution

The RADIO project identifies the popularity that BLE attracts and foresees the benefits that modern IoT and Ambient Assisted Living (AAL) application domains will gain from the upcoming BLE mesh networking support. Therefore, RADIO designs a mesh mechanism that will be integrated in distributed sensor/actuator devices scattered across the RADIO AAL environment.

3.2.1 Network Formation

After a thorough study of the existing approaches, the RADIO BLE mesh networking mechanism will be based on the principles of BLE connectionless communications through advertisements and scanning.

Advertising is the act of broadcasting data and it aims in device discovery and data publishing. The advertising mechanism involves 2 possible types of data packets that can be transmitted. The mandatory packet is the advertising packet while a node can optionally send a Scan Response packet. These two types of packets are structured mainly by the advertiser address and 31 bytes of payload as presented in Figure 8. During the normal operation, the BLE advertiser constantly broadcasts the advertising packets within an advertising interval bounded by a minimum and maximum value. These intervals typically may range from 20ms to 10.24s.

During the network formation phase, the RADIO mesh mechanism will utilize the advertisement packets along with the broadcasting technique in order to achieve the network formation and route discovery. During the initialization of the network, each node broadcasts an advertising packet, which is the route discovery packet (route request - RREQ) in the context of the RADIO mesh. The RREQ messages are forwarded by each adjacent node until a pair of nodes exchange RREQs. Then a RREP message which contains the repliers address is sent backwards. During the reception of the RREPs, the respective neighbors table of each node is built. An instance of the neighbors table construction is presented in Figure 8.

This flooding approach replicates every message at every relay node and is expected to deliver near optimal delivery probability. Furthermore, it doesn't require any knowledge about the network during the design time. The increased resource consumption can be tolerated since flooding occurs once during the network initialization. Furthermore, the deployment scale of the RADIO mesh network is not expected to expand more than a number of nodes for a small to medium network size. Scalability is accomplished since the route discovery can be performed on a new node's entrance.

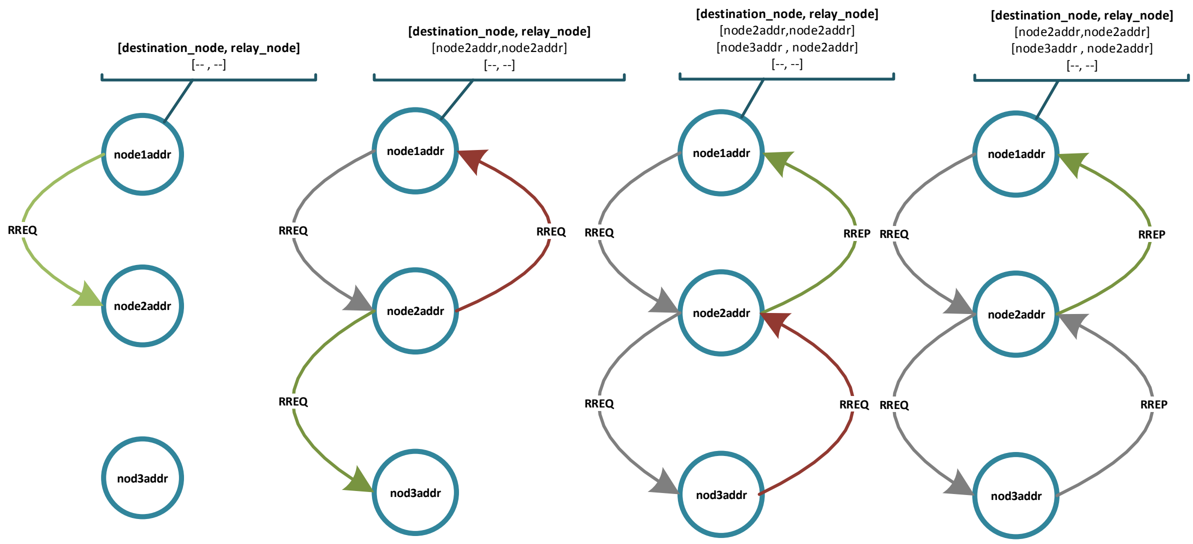

Figure 9: Network discovery mechanism

The presented network discovery approach will be evaluated during the software implementation of the RADIO mesh layer and thorough evaluation results will be included in following versions of this deliverable. Furthermore, possible optimizations of this approach will be explored.

3.2.2 Message Forwarding

After the network discovery is completed by every node of the network every node has knowledge about its surrounding neighbors. This knowledge will be utilized by the RADIO mesh mechanism either in the network or the application layer. The nodes now are ready to start forwarding their data messages. The approach followed in every version of BLE mesh released by the industry so far is on the connectionless mode of BLE and advertisements are used as data carriers.

The first approach of the RADIO mesh will forward data messages through rebroadcasting. Rebroadcasting works by flooding all messages to all nodes in the network through broadcasts. Nodes are in scanning mode and when an advertisement is received, the receiver rebroadcasts it to its neighbors (Figure 9). The process is repeated on every node and it is completed when every node receives the respective message. In order to avoid the continuously rebroadcasting of the same message, a versioning mechanism is implemented and runs on every receiver node. Upon the generation of the message on the source node, a version indicator is paired with the respective value and propagated along the network. Each relay node that receives the message stores it in a local data table. On every reception of a message from the same source and sensor, the relay node checks the version of the packet and propagates it to its neighbors if the received message version differs from the local. The message broadcasting process is completed when every node in the network received the message.

While broadcasting may increase the packet delivery ratio due to route redundancy it has a major drawback which highly affects the network performance under various network traffic loads and node density. Bluetooth Smart uses 40 RF channels in the ISM band (2.4GHz). These RF channels have center frequencies 2402 + k*2MHz where k ranges from 0 to 39. Advertising utilizes three of them specifically channel 37 (2402MHz), 38 (2426MHz) and 39 (2480MHz). Due to broadcasting, the network is flooded with redundant transmissions. As a result, the poor utilization of frequency bands may degrade network performance and overall power consumption. Details on the performance statistics will be explored later in the chapter and enhanced on updated versions of this deliverable.

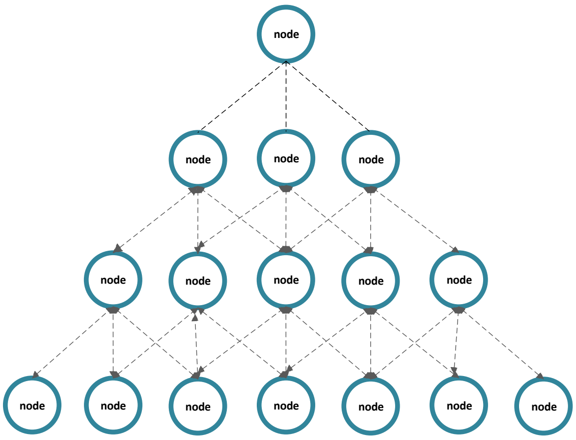

Figure 10: Message Forwarding with broadcasting

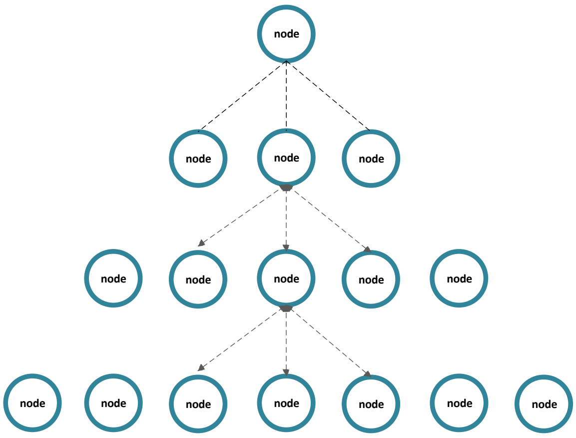

Figure 11: Message Forwarding with selective broadcasting

During the development and evaluation phase of the RADIO mesh a selective broadcasting policy will be implemented and evaluated. As described earlier, during the network phase, the nodes discover their neighbors and they store this knowledge locally. This knowledge is used to build the respective forwarding mechanism depending on the destination of their transmissions. These routing tables will be used by the RADIO mesh in order to perform the selective broadcasting mechanism. The 29 bytes of payload are used to encapsulate the address of the destination node, the sensor model (described by the data type and data value) and the message version (described later). The application domain where RADIO mesh will be deployed handles simple numeric sensor values that do not demand large packet payloads to carry them through the network. Therefore, the 29 bytes of the BLE advertisement packet is considered adequate for similar applications.

During the operation of the RADIO mesh with the selective broadcast enabled, every parent node that receives a message by the child node parses the payload of the packet and checks the packet's destination node. If the particular destination node is registered in its routing table, the message is rebroadcasted to its neighbors. In case the relay node doesn't retrieve a route to the destination node it discards the packet from its queue. Figure 10 and Figure 11 give a visual representation of the traffic generated by the broadcasting and selective broadcasting transmissions. The figures show how the traffic load differentiates among the two approaches. Particularly we observe that selective broadcast relaxes the traffic load significantly, while at the same time retains a degree of route redundancy that benefits the packet delivery ratio without abusing the network resources.

Further enhancements on the forwarding mechanism of the RADIO mesh will be explored. A major improvement of the network utilization will be the use of directed advertisements instead of undirected advertisement for the broadcast events. Through the directed advertisements, the node can direct the packet transmission towards a specific scanner device (network node) instead of broadcasting them. In essence the transmission model of the BLE mesh network is becoming unicast in favor of network resources, Quality of Service (QoS) and power consumption. The implementation details of this model will be described in an updated version of this deliverable.

4 SMART HOME – ROBOT DOMAIN BRIDGING TECHNIQUES

In the context of RADIO, the smart home service and the robot service are integrated into a unique solution. The data communication between the smart home and the robot will be done through the smart home controller or the IoT platform by using a client-server technology. The client system requests services provided by the server.

As designed in Deliverable 5.1, the components of the RADIO ecosystem are the smart home platform, IoT platform, and the robot platform. The smart home platform contains sensors and actuators deployed in the home location and the smart home controller (SHC). The IoT platform is a collection of smart home services outside the boundaries of the smart home that aims to provide more complex automation functionality, such as the request of historical data by the robot. Finally, the robot is responsible of monitoring and assisting patients in carrying out activities of daily living.

4.1 Integration between the Platforms Smart Home and IoT

The integration between the Smart Home platform and the IoT platform was already developed in order to provide the following services:

1. Remote management of the sensors and actuators: upload/download sensor values, upload/download sensor and actuators status, and download sensors of an installation. The SHC is responsible of (i) acquiring data from sensors by using communication protocols such as WiFi, Z-Wave (ii) storing the last state/values from the sensors and actuators, and (iii) sending this information to the IoT platform to be stored as historical data when new information arrives. The sensor information transmitted and stored in the SHC is the name, the specific location of the sensor inside the home, the type (magnet, presence, thermostat, etc.), the value measured, and the current status.
2. Management of the data generated by the sensors.
3. Real-time event communication between the IoT platform and the smart home: This event service API relies on ASP.NET SignalR technology that provides real-time web functionality in order to support a “server push” feature. The model of communication between clients and servers supported by the SignalR API and implemented in the RADIO context is the Hubs communication model.
4. Secure communication: Standard security mechanisms such as authentication mechanisms, self-signed certificates and HTTPS protocols have been developed.

A more detailed description of the integration between these platforms was given in Chapter 6 of Deliverable 5.1. The source code of the Java API and C# API can be found as an annex to D5.1 [RADIO D5.1].

4.2 Integration between the Platforms Smart Home / IoT and Robot

The integration between the smart home, the IoT platform and the robot platform enables the addition of new functionalities to the RADIO ecosystem. Mainly, the robot will be able to ask for information about the smart home in order to:

- Gain new insights about the status of the patient.
- Carry out some specific action by itself in order to ensure patient safety.
- Perform changes by using the actuators (switch on/off smart plugs, switch on/off lights, dimming of lights, thermostat target temperature, open/close doors, shadows, curtains, etc.) to ensure patient comfort. This task will require that the robot sends a command to the SHC, i.e. the robot will act as a server

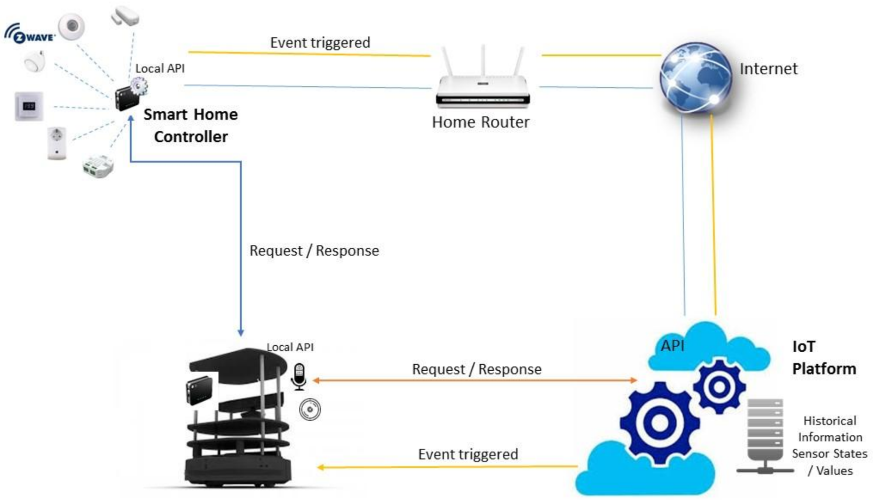

Figure 12 Overall communication architecture between the RADIO Robot and the RADIO Home Platform

The further integration between the platforms smart home and robot requires the development of new communication protocols based on the robot's tasks:

1. **Polling protocol:** The robot acts as a client polling the SHC for information that, in turn, sends its data only in response to the poll request. This can happen when the robot needs information about the home status on a regular basis to complete information about the status of the patient. The SHC acts as a server in this situation.
2. **Real time event-triggered:** An anomaly is detected by the SHC (or the IoT platform) and the information or a specific trigger is sent to the robot to take some specific action. The SHC acts as a server in this case.
3. **Request of historical data:** In this case, the IoT platform acts as a server. Since it is highly desirable not to drain the battery of the robot in this case, a number of query optimisation methods of data selection and data aggregation are available in order to decrease the amount of exchanged information between the robot and the IoT platform. Less information to be transmitted will imply less time to be devoted to this task and, therefore, battery power saving. The database optimisation techniques are
    - Data selection: A filtering algorithm is used to select a subset of the data. The robot can ask for specific information by using the sensor type or a date range.
    - Data aggregation: This protocol allows replacing groups of values with summary statistics based on those values. In particular, data can be merged by the sum or arithmetical mean of all aggregated values. These data aggregation techniques were developed in a big data and cloud environment. Further information is provided by task 4.2 'Embedded device design and development'.

Figure 11 shows the communication architecture between the RADIO home platform and RADIO robot.

The overall communication relies on a strong collaboration between the smart home and robot developers in order to use robust and efficient APIs and to define new data aggregation techniques for optimal information extraction.

4.3 Forthcoming Potential Functionalities

As mentioned earlier, the development of this overall integration within the RADIO context will provide a number of potential functionalities such as:

- To recognise and assist a wider number of ADLs by using smart home information.
- To combine data acquired from both platforms. The robot platform will detect activity patterns that will be complemented with data coming from the smart home platform capable of modelling user behaviour based on household energy consumption data.
- To explore the correlation between the household energy consumption data and a user's wellness. The household energy consumption pattern anomalies represent changes in user behaviour.
- To increase the robot's functionalities, e.g. allowing the control of the smart home actuators by the robot.
- To improve the smart home's functionalities by using data acquired by the robot, e.g. improving the smart lighting system by knowing the indoor position of the patient.

4.4 Benefits of an Integrated System

An integrated system promotes efficiency and reduces costs in terms of:

- Facilitating the management of the sub-systems from a unique service.
- Improving response time.
- Data collected by different systems lead to better decision making.

A unified data model reduces the complexity of matching, cleaning and preparing all data for different applications.

5 Advanced Gateway Design Supporting Heterogeneous Low Power Wireless Technologies

5.1 Introduction

Envisioning RADIO as a continuously evolving, flexible Cyber Physical System (CPS) platform, regarding the communication perspective, typically, short range wireless communication protocols enable data aggregation to a central point (indicated as the Gateway). Although a plethora of different communication technologies (mainly originating from WSN research domain) are available, they offer diverse characteristics exhibiting high degree of incompatibility. In that respect a highly efficient gateway design has been designed and explored in the context of RADIO able to support the most prominent short range wireless communication technologies such as IEEE 802.15.4 [802.15.4 Spec], ZigBee [ZigBee], Bluetooth [Bluetooth], BLE [BLE] and Z-Wave [ZWave]. Also, a critical goal of the design is to facilitate the continuous development and integration of new solutions. Communication complexity however, is also related to efficient data transfer between the gateway and remote installations like service providers, databases, graphical user interfaces etc. Consequently, presented gateway design supports both http based communication facilitating well-known technologies such as REST, SOAP as well as more contemporary approaches such as message passing communication aiming to support increased communication complexity.

Furthermore, the increased functional complexity calls for new processing capabilities in the future gateway designs. In order to address the respective challenge, the explored Gateway design highlights the ability to support data acquisition by different modalities and using different communication technologies to be synchronized, homogenized and processed. In this way, sophisticated load balancing, data merging, QoS, prioritizing and many more mechanisms can be supported. This approach also facilitates real-time data processing and event detection which is of paramount importance in demanding applications such as medical and industrial deployments.

The RADIO platform intends to be a continuously evolving solution that is able to cover major CPS including end-to-end data communication, processing, storage and representation requirements. In this context and focusing on the RADIO home automation environment, starting from the left hand side of Figure 13, an efficient, flexible and extendible approach is targeted so that any kind of heterogeneous sensor or actuation modality is aggregated at the proposed gateway. A critical goal here is to support heterogeneous technologies in a homogeneous way regardless of being connection or connectionless oriented, supporting or not supporting multi-hop packet transmission, supporting QoS mechanisms or not, offering high throughput capabilities or not etc. Then, the next important conceptual design choice concerns the way data, events or/and commands can be exchanged between the gateway and the backend infrastructure (i.e. the RADIO IoT platform). Once again, the main goal is to focus on maximum flexibility and extendibility so as both complex modalities and complex applications can be addressed. Consequently, apart from the typical HTTP APIs, a message passing API is also supported and provided. Based on these APIs, the developer can design and implement services tailored to the needs of specific applications.

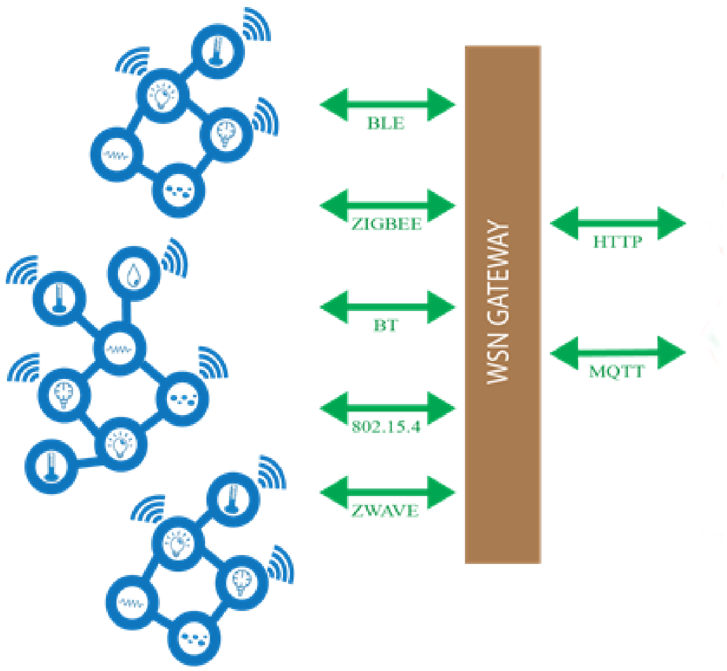

Figure 13 Conceptual Diagram of the GW Entity

In the context of the presented implementation, WSN sensors communicate through technologies such as Bluetooth and ZigBee, using the MQTT-SN [MQTT-SN] protocol, and connect with the Gateway in order to communicate with the IP Network, as well as interacting with sensors based on different wireless communication technologies. The gateway is an intermediate component where data are collected and processed before being forwarded to the core network for further processing.

In most monitoring WSNs development and deployment, one of the most vital goals is to collect and aggregate the sensor data (e.g., environmental data, patient data, battlefield data) for analysis. To this end, the development of a WSN gateway is critical for data gathering by diverse WSNs in real-world scenarios. The focus is to design and implement a fully user-configurable WSN gateway architecture for effective and efficient data collection; this will enable easy integration of different WSNs applications to the gateway and adhering to different communication technologies. The WSN gateway will be able to parse and analyze dynamic packet formats with variable packet sizes. Many message passing protocols [AMQP], [STOMP], [Banks 2014] have been created over the years, but we need a simple and lightweight protocol. In that respect, MQTT-SN, has been selected as the preferred communication protocol in order to support communication heterogeneity in WSN, with dynamic packet formats in a homogeneous manner. MQTT-SN is a publish/subscribe messaging protocol that extends the well-established *Message Queue Telemetry Transport (MQTT)* protocol in order to cope with the specific constraints of WSNs, such as resource-limited and battery-operated devices, low network bandwidth and high link failures. It provides an intuitive application programming interface that hides completely the complexity of the underlying networking technologies. MQTT-SN is a highly developed protocol, and the one with the most standardization attempts for WSNs [Robinson, 2005]; it has been widely used for remote monitoring applications [Ullas, 2014], messaging applications and a range of home automation applications [Erratt, 2013].

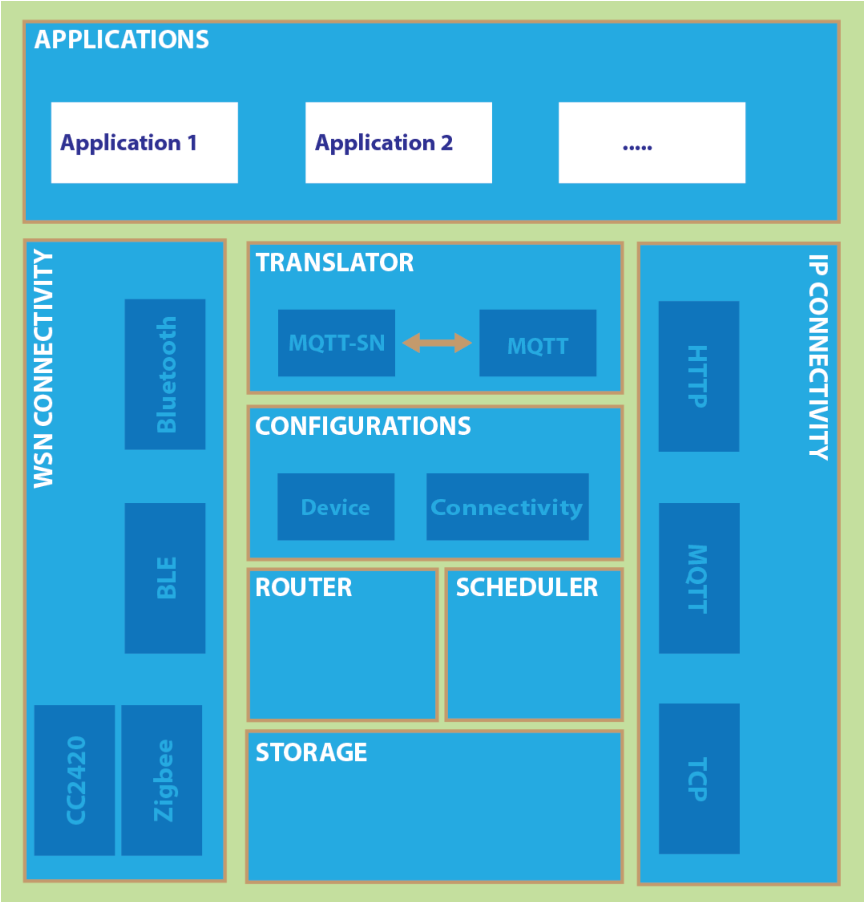

Figure 14 Gateway Architecture

5.2 Gateway Implementation Analysis

The gateway is the main aggregation point for the data collected from sensors in the physical environment, which makes it a fundamental component for the network. For the implementation of the gateway the OSGI [Liu 2011] technology has been selected, in order to accomplish modularity and extensibility. OSGI is a module management framework for Java programming language. Every module, namely Bundle, can be installed at runtime and uninstalled as well, and can be accesses by other bundles through OSGI Service Registry. A high level architecture of the gateway is depicted in Figure 14.

At the top level of the architecture, all user-defined applications that will run in the gateway are placed. An example of such application, is a monitoring application for the lights of a house. Moving towards lower layers of the software stack, the proposed gateway defines networking modules for handling communication requirements as well as a storage module for handling storage requirements. The Translator module is responsible for translating MQTT-SN messages originated from WSN, to MQTT compliant messages in order to forward them to the IP network.

The Configurations module provides all configuration parameters related to the gateway. As depicted in Figure 14, there are two types of configurations, one corresponding to the device and one to the connectivity. Device configurations are internal gateway parameters, such as enabled applications. Connectivity configurations are related to the WSN and IP network. An example of such configuration is a network coordinator connection parameter, like the connection port. Some of the basic configuration parameters of the gateway are described in Table 2 below.

Parameter	Explanation	Values
gwid	Gateway identifier, Must be the same with that name that stored in Storage and Coordinator	gateway-0001
type	Define the type of gateway, for more info see *Chapter 3.2*	aggregate | transparent
coordinator	Information about the connection with the coordinator of the network	{ "host": "domain", "port": 2181, "username": "", "password": "" }
interfaces	List with connection interfaces for the WSN, can be more than one.	1. ble 2. bt 3. zigbee 4. 802154
connection_mode	Gateway connection mode to WSN, explained below.	1. force_connect 2. stand_by 3. invisible 4. closed
communication_protocols	List with connections to the backend network, can be more than one.	1. mqtt 2. amqp 3. stomp 4. websocket 5. soap 6. http
data_process	Define how the gateway will be handle the data from the sensor networks, explained below	1. pass_through 2. buffering 3. calculate
subscriptions	Contains a list with predefined subscriptions to topics or queues of the gateway	["/wsn/framework"]
edb	Embedded database name	gatewayedb

Table 2. Gateway Configurations

Gateway parameter	Explanation
force_connect	The gateway will start searching for devices in the network, and when it finds a mote it will try to connect with it. This is the default connection mode for the gateway.
stand_by	The gateway will send a broadcast message in order to inform the network motes for its presence, and then it will wait from sensor motes to send a connection request.
invisible	The gateway will be online, but it will not send a broadcast message in order to inform the network for its presence. Only the devices that know its existence will try to connect with the gateway.
closed	The gateway will be online; its existence is unknown and no connections can be established.

Table 3. ATLAS Gateway connection modes

5.2.1 Gateway connection mode

The gateway connection mode defines how the gateway behaves with the wireless sensor network. As mentioned in the table above, the gateway can be in four different connection modes.

5.2.2 Data processing

This configuration parameter informs the gateway how to handle data derived from the wireless sensors network. A Gateway has three different modes for the data processing:

1. pass_through, in this mode every incoming data will be passed directly to the IP network.
2. buffering, in this mode the incoming data will be stored locally to the gateway. The gateway can be configured to operate in this mode during start-up or can be switched when the connection with IP network lost.
3. process, in this mode the gateway will process the incoming data according to the given implementation, and then according to the rules defined it will process the incoming data.

5.2.3 Embedded DB

Our solution provide an embedded database (DB) for a series of actions that will persist in the gateway. We choose SQLite [Bi 2009] as it is a lightweight database and it realizes a complete and embeddable database engine without additional components, which is especially suitable for embedded applications.

In order for gateway modules to communicate with embedded DB, we expose a very simple API for gateway internal components to use the database, which consists of five methods:

- save, add a new value to a collection.
- update, update an existing value in a collection.
- delete, delete an existing value in a collection
- get, get a specific value from a collection
- fetch, get a list of values from a collection

Data organized using the traditional SQL model, using tables linked together in order to provide a robust database schema. A simplistic example of such table is the devices table, where we can store locally the sensor devices that are currently connected to the Gateway, together with related information about the device.

The most important actions that will be performed by the embedded DB are:

1. Store the WSN devices and their properties.
2. Devices subscriptions.
3. Internal gateway rules, such as handlers for the data.
4. Buffering functionality for WSN sensor data.
5. Data formats, to read the data locally.
6. Routing rules.

5.2.4 Main Gateway modules

The **Router module** is an embedded mediator in the Gateway which is responsible for forwarding messages to the appropriate endpoints in order to be published either to the WSN or to the IP network. For example, one of the Router module's functionalities is to set up the communication channel that the received data will be forwarded to.

The **Scheduler module** is responsible to carry out repetitive or individual tasks, defined in schedule based or event based conditions.

The IP **Connectivity module** is responsible for setting up and maintaining the connections with the IP network. As depicted in Figure 4, the module can maintain a connection with the Message Broker, using the MQTT adapter, as the primary communication technology. It also contains an HTTP adapter as an alternative communication technology.

The WSN **Connectivity module** is responsible for initializing, setting up and maintaining the wireless adapters that will be used for the communication with the WSN. As shown in Figure 4, the gateway contains adapters for Bluetooth, BLE, 802.15.4 and ZigBee. Each adapter will start to operate according to one of the connection modes described before; in parallel, it will be responsible for establishing connections and collaborating with the WSN; finally it will terminate the connections if needed.

6 REFERENCES

[802.15.4 Spec] http://standards.ieee.org/about/get/802/802.15.html

[AMQP] AMQP Specification v1.0, 2011

[Banks 2014] Banks, Andrew and Gupta, Rahul. MQTT Specifications v3.1.1. s.l. : OASIS, 2014.

[Bi 2009] Chunyue Bi, Research and Application of SQLite Embedded Database Technology, Published in, Journal WSEAS Transactions on Computers, January 2009

[BLE] Bluetooth SIG (Hrsg.): Specification of the Bluetooth System: Covered Core Package version:4.0, Juni 2010

[Bluetooth] Bluetooth, Specifications (SIG), 2001, Version 1.1

[CM5000] http://www.advanticsys.com/shop/mtmcm5000msp-p-14.html

[CodeBlue] http://fiji.eecs.harvard.edu/CodeBlue

[CSRmesh] https://wiki.csr.com/wiki/CSRmesh

[Erratt 2013] Newlyn Erratt et.al., "The Design and Implementation of A General WSN Gateway for Data Collection", IEEE Wireless Communications and Networking Conference (WCNC): SERVICES & APPLICATIONS, 2013, pp. 1256-1278.

[Levis, 2011] Levis, Philip, et al. The trickle algorithm. No. RFC 6206. 2011.

[Liu 2011] Jinzhao Liu; Xiaojuan Lu ; Dan Wang ; Xin Liu ; Yongqiang Lu ; Yu Chen; "LIR-OSGi: Extends OSGi to support distributed and heterogeneous ubiquitous computing system", Published in: Pervasive Computing and Applications (ICPCA), 2011 6th International Conference on Port Elizabeth, October 2011

[MoviSens] http://www.movisens.com/en

[MQTT-SN] Truong, Andy Stanford-Clark & Hong Linh. MQTT for Sensor Networks (MQTT-SN), Protocol Specification v1.2. 2013.

[OpenMesh] https://github.com/NordicSemiconductor/nRF51-ble-bcast-mesh

[OpenThread] https://github.com/openthread/openthread

[Part15.4] LAN/MAN Standards Committee of the IEEE Computer Society. IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs), October 2003

[RADIO D5.1] RADIO Deliverable 5.1. *Architecture of the RADIO Ecosystem I*. April 2016. URL http://radio-project.eu/deliverables#d5.1

[radio_pulse] http://www.radiopulse.co.kr/eng/main.html?mode=02_07 -> data transfers up to 1Mbps

[Revoing2011] Revoking Networks "Advanced User Manual" Version 4.77 2/3/2011

[Robinson 2005] Robinson, J.M.; Frey, J.G.; Stanford-Clark, A.J.; Reynolds, A.D.; Bedi, B.V. Sensor Networks and Grid Middleware for Laboratory Monitoring. In Proceedings of the First International Conference on e-Science and Grid Computing, Melbourne, Australia, 5–8 December 2005; pp. 562–569.

[Shimmer] http://www.shimmer-research.com/

[STOMP] STOMP Specifications, v1.2, 2015

[Thread] http://threadgroup.org/

[TI SensorTag]

http://www.ti.com/ww/en/wireless_connectivity/sensortag2015/?INTC=SensorTag&HQS=sensortag

[Ullas 2014] Ullas B.; Anush S.; Roopa J.; Govinda Raju M.; "Machine to Machine Communication for Smart Systems using MQTT", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 3, Issue 3, March 2014

[ZigBee] Zigbee specification, January 2008

[ZWave] OpenZwave. (n.d.). Retrieved June 2013, from openzwave Google code site: https://code.google.com/p/openzwave/