Wireless Sensor Networks: Performance Analysis in Indoor Scenarios

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Abstract **-We evaluate the performance of realistic wireless sensor networks in indoor scenarios. All of the considered network is formed by nodes using the ZigBee communication protocol. This paper gives a short overview of the IEEE 802.15.4 and analysis the properties and performance of IEEE 802.15.4 through measurement of the received signal strength indicator (RSSI) and packet error rate (PER).**
We analyze the behavior of the RSSI for different distances and scenarios with direct transmissions between the remote nodes.

***Keywords* - Zigbee, RSSI, PER**

I. Introduction

Wireless sensor network consists of a large number of sensor nodes that may be randomly and densely deployed. Sensor nodes are small electronic components capable of sensing many types of information from the environment, including temperature; light; humidity; radiation; the presence or nature of biological organisms; geological features; seismic vibrations; specific types of computer data; and more. Recent advancements have made it possible to make these components small, powerful, and energy efficient and they can now be manufactured cost-effectively in quantity for specialized telecommunications applications. Very small in size, the sensor nodes are capable of gathering, processing, and communicating information to other nodes and to the outside world. Based on the information handling capabilities and compact size of the sensor nodes, sensor networks are often referred to as "smart dust."

Distributed wireless microsensor networks are an important component of ubiquitous computing, and small dimensions are a design goal for microsensors. The energy supply of the sensors is a main constraint of the intended miniaturization process. It can be reduced only to a specific degree since energy density of conventional energy sources increases slowly. In addition to improvements in energy density, energy consumption can be reduced. This approach includes the use of energy-conserving hardware. Moreover, a higher lifetime of sensor networks can be accomplished through optimized applications, operating systems, and communication protocols.

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Particular modules of the sensor hardware can be turned off when they are not needed. Wireless distributed microsensor systems enable fault-tolerant monitoring and control of a variety of applications. Due to the large number of microsensor nodes that may be deployed, and the long system lifetimes required, replacing the battery is not an option. Sensor systems must utilize minimal energy while operating over a wide range of operating scenarios. These include power-aware computation and communication component technology, low-energy signaling and networking, system partitioning considering computation and communication trade-offs, and a power-aware software infrastructure.

The past several years have seen the rapid growth of wireless networking. So far wireless networking has been mainly focused on highdata- rate and relatively long range applications.

The effort to increase the data rate can be clearly seen in the development of IEEE 802.11 standard series, from the initial 1–2 Mb/s in 802.11 to as high as 54 Mb/s in 802.11a and 802.11g (Fig. 1). Bluetooth (IEEE 802.15.1) is the first well known standard facing low-data-rate applications. The complexity of Bluetooth makes it expensive and inappropriate for some simple applications requiring low cost and low power consumption. Bluetooth also lacks flexibility in its topologies. Besides star topologies or so-called piconets, scatternets are used in Bluetooth for supporting peer-to-peer networks, but research work has shown that scatternets face scalability problems.

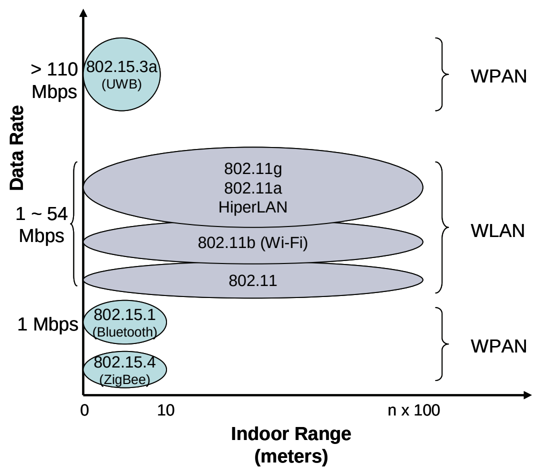

Fig. 1 Wireless networking

As more and more low-cost high-quality devices appear on the market and new applications emerge every day, short-range wireless personal area networks (WPANs), both low and high-data-rate, are on the horizon. Two major efforts of IEEE are underway to boost the development of WPANs. One is the specifications of IEEE 802.15.3a, also known as ultra wideband (UWB), for high-rate WPANs. The other is the specifications of IEEE 802.15.4 (referred to as 802.15.4 here) for low-rate WPANs (LR-WPANs). In this paper we concentrate on low-rate WPANs, specifically IEEE 802.15.4.

One of the newest standards for wireless sensor networks, with significant power savings, has been called ZigBee.

The reminder of the paper is organized as follows: section II gives an overview of the IEEE 802.15.4 standard. In section III we present results from measurements made to characterize the basic behavior of IEEE 802.15.4 in indoor environments. Section IV concludes the paper.

II. OVERVIEW OF THE IEEE 802.15.4

The IEEE 802.15.4 standard has been adopted by the Zigbee Alliance for wireless personal area network technology. The reference model, depicted in Fig. 2, shows the various layers of the Zigbee wireless technology architecture the relationship of the IEEE 802.15.4 standard to the Zigbee alliance MAC layer protocol model. These layers facilitate the features that make Zigbee very attractive: low cost, very low power consumption, reliable data transfer, and easy implementation. Using the IEEE 802.15.4 specifications, the alliance focuses on the design issues related to the network, security and applications layers.

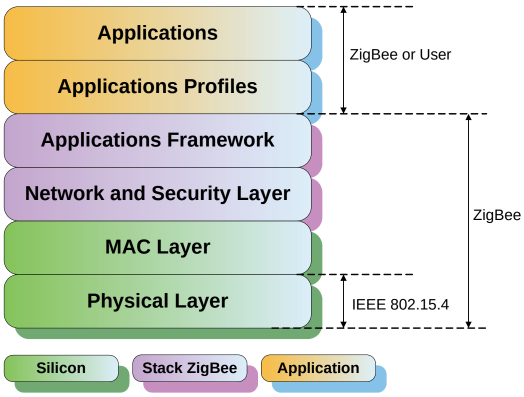

Fig.2 IEEE 802.15.4 and Zigbee reference model

The ZigBee technology is based on the IEEE 802.15.4 standard and guarantees (theoretically) a transmission data rate equal to 250 kpbs in a wireless communication link. Three transmission bands are allowed by the ZigBee standard: (i) 2.4GHz, (ii) 868 MHz, and (iii) 916 MHz. While the first transmission band is available worldwide, the second and third are available only in Europe and USA, respectively.

The IEEE 802.15.4 supports two PHY options. The 868/915MHz PHY known as low-band uses binary phase shift keying (BPSK) modulation whereas the 2.4GHz PHY (high-band) uses offset quadrature phase shift keying (OQPSK) modulation. Both modulation modes offer extremely good bit error rate (BER) performance at low Signal-to-Noise Ratios (SNR). The IEEE 802.15.4 physical layer offers a total of 27 channels, one in the 868MHz band, ten in the 915MHz band, and, finally, 16 in the 2.4GHz band. The raw bit rates on these three frequency bands are 20 kbps, 40 kbps, and 250 kbps, respectively. Unlike, for example, Bluetooth, the IEEE 802.15.4 does not use frequency hopping but is based on direct sequence spread spectrum (DSSS). In this case the measurements are made in the 2.4GHz frequency band as that is the area where inter-technology problems can be prominent and due to the fact that it is a tempting for larger scale sensor deployments.

Three different kinds of nodes can be used in a wireless network, according to the ZigBee specifications: (i) a *router*, (ii) a *coordinator*, (iii) and an *end device*. The coordinator can create the network, exchange the parameters used by the nodes to communicate (e.g., network ID, beginning of transmitted frame, etc.), relay packets received from remote nodes towards the correct destination, and collect data from the sensors. Only a single coordinator can be used in a network. Router, instead, relays the received packets and the control messages (in order to increase the network diameter), manages the routing tables and, if required, can also collect data from a sensor. The main difference between a coordinator and a router is that the former can create the network, while the latter cannot. Both these types of nodes are referred to as full function devices (FFDs): they can develop all the functions required by the ZigBee standard in order to set up and manage the communications. On the other hand, end devices, also referred to as reduced function devices (RFDs), can act only as remote peripherals, which collect values from sensors and send them to the coordinator or other remote nodes. However, RFDs are not involved in network management, and therefore, cannot send or relay control messages.

According to the ZigBee standard, three different kinds of network topologies are possible: (i) star, (ii) cluster-tree, and (iii) mesh.

(i) In a *star* network, there are a coordinator and one or many RFDs (end nodes) or FFDs (routers) which send messages directly to the coordinator (up to 65536 RFDs or FFDs).

(ii) In a cluster-tree topology, instead, there are a coordinator which acts as a root and either RFDs or routers connected to it, in order to increase the network dimension. The RFDs can only be the leaves of the tree, whereas the routers can also act as branches. In a cluster-tree topology, a beacon structure can be employed in order to obtain an improved battery conservation.

(iii) In a mesh network, any source node can talk directly to any destination. The routers and the coordinator, in fact, are connected to each other, within their transmission ranges, in order to ease packet routing. The radio receivers at the coordinator and routers must be “on” all the time.

We analyzed the performance of realistic wireless sensor networks in various indoor scenarios: scenario with direct transmissions between the remote nodes. All the experiments are conducted in an indoor environment, so that there are reflections due to walls and furniture. The measurements are made for distance of 35metres, where the measurements are taken on every 2 meters.

III. Received Signal Strength Indicator (RSSI) Measurements

The experimental setup for a ZigBee network is made by using ZigBeeTM Enabled Board for Radio Applications (ZEBRA) belonging to the Freescale Company. The ZEBRA modules are shown on Fig.3.

The ZEBRA module works in the worldwide free available 2.4 GHz ISM Band. It is made to receive or transmit data conform to the standard IEEE 802.15.4. The module is made out of the radio chip MC13192 as well as the micro controller HCS08GT60 from Freescale Semiconductors and an integrated antenna. The data transfer rate goes up to 250kBps, the radiation power is 1mW (low power version) or 30mW (high power version). There exist 16 different channels with 5 MHz Bandwidth (each of them). For undisturbed transmission the module uses DSSS (direct sequence spread spectrum). The sensitivity is typically –85 dBm. With the provided software it is possible to create application for the ZEBRA module. The controller HCS08GT60 owns 60kB flash memory which can be used as program or data memory. 4kB of it in the upper memory area are reserved for the Freescale Bootloader. This enables flashing by the serial port. If an external BDM interface is used to flash the module (e.g. USB HCS08/HCS12 Multilink of P&E Microcomputer Systems, Inc.), the reserved upper memory area can also be used for the application.

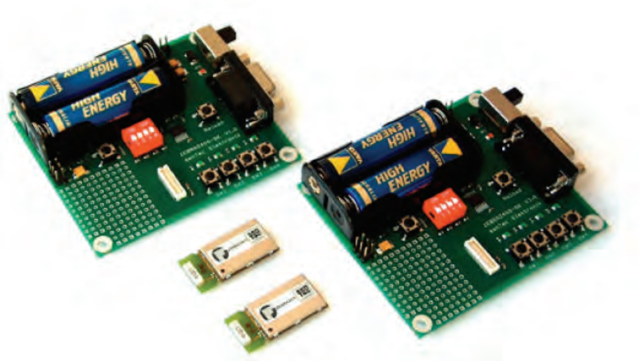

Fig. 3 Zebra modules

The wireless UART application realizes a bidirectional serial RS 232 point to point radio connection. The communication settings are 38.400 kbps, 8 Bit, 1 Stop bit, no flow control. The PER Test (Package Error Rate) simply sends 100 time different data packages from the transmitter to the receiver. The packet length changes from 3 Bytes (smallest possible) to 133 Bytes (longest possible) in 4 steps. So 400 data sequences are sent in 4 different package sizes. To set the ZEBRA module to the transmit mode, any of the four buttons have to be pushed during power on or during reset. Anyway the default mode is receiving mode.

In particular, the impact of the distance between the two employed nodes is evaluated. Radio is an essential component of a sensor node. The basic characteristic of radio is radio signal strength (RSS). Usually, signal strength is expressed in dBm units, which is the dB expression of power referenced to 1mW so that higher dBm value corresponds to higher power. In current sensor nodes, such as ZEBRA modules, their radios can report the Received Signal Strength Indicator (RSSI) for each received packet in dBm units. The RSSI is a very important indicator for wireless networks, since it can be used to characterize the channel status. Generally, the received signal strength gradually decreases as the receiver moves away from the transmitter. The relationship between RSS and transmitter-receiver (T-R) separation distance is described as a propagation model.

In order to obtain experimental measurements, the topology in Fig. 4 has been considered, using two nodes directly connected: a coordinator and an node.

Fig. 4. Direct transmission between nodes

The measurements for PER and RSSI in the indoor scenario are made up to 35 meter distance between the transmitter and the receiver and the measurements are taken on every 2 meters with 4 different packet sizes. All of these measurements were performed in the hall inside the Department of Computer Science and Automation at Technical University in Ilmenau, Germany. The results taken in indoor scenario between the nodes are shown in the table I.

TABLE I

Distance	Strength(dBm)
0	-85,02700175
2	-85,51571974
4	-86,37589786
6	-86,58011397
8	-86,52536419
10	-87,55188586
12	-87,59063188
14	-87,28597243
16	-87,2607487
18	-87,78585328
20	-87,58609143
22	-88,13781078
24	-87,94139356
26	-87,98512533
28	-88,30588669
30	-88,05908455
31,7	-88,00235789

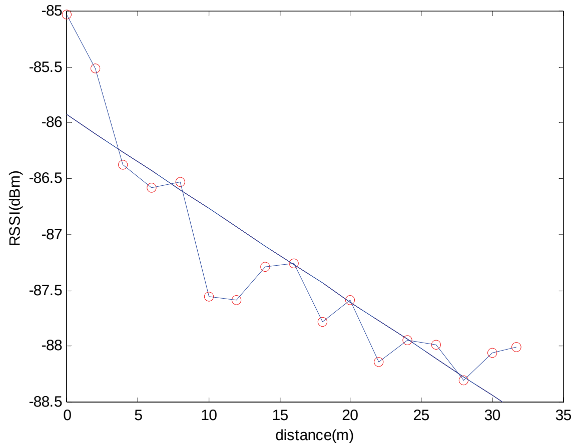

Fig. 5 Received Signal Strength Indicator (RSSI) as a function of distance between nodes

On fig. 5, the measured RSSI is shown as a function of the distance between the two nodes. Solid lines represent the effective values measured by the coordinator, whereas the dashed lines are obtained by linearly interpolating the collected experimental values. The transmit power Pt is 0 dBm. The difference between experimental values and dashed lines can be associated with the presence of reflection phenomena (due to walls and furniture) and obstruction phenomena (due to people crossing the rooms). In logarithmic scale, the RSSI decreases linearly, as expected, as a function of the distance.

IV. Packet Error Rate (PER)

The Packet Error Rate corresponds to the ratio between the number of erroneous received packets and the total number of transmitted packets. The experiment is about the measurement of the PER, as a function of the distance, in a short communication range, considering distances between 1m and 35 m. The average PER is around 0.38. This high PER value is mainly due to synchronization problems of the nodes and internal exchange of messages at the control level of node.

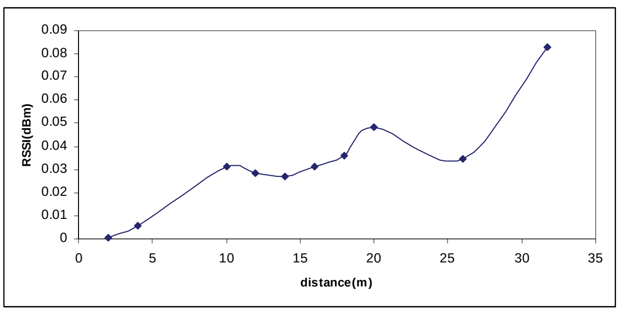

Fig. 6 Measured Packet Error Rate (PER) as a function of distance between nodes

The results of the last performance analysis of a ZigBee network, in terms of PER, is shown in Fig. 6, where the "connectivity indicator," defined as PER, is shown as a function of the distance between the two transmitting nodes. The network topology adopted in this experiment corresponds to that in fig. 4. According to theoretical results, an ad hoc wireless network has a bimodal behavior. At short distances, there is full connectivity and communication can be sustained. When the distance between the two nodes increases beyond a threshold value, instead, connectivity falls down rapidly and between the two nodes the packet loss is enormous. The critical maximum distance for connectivity in indoor environment is around 20 m. This phenomena is due to strong multipath phenomena in indoor scenario.

V. Conclusion

The increasing interest in wireless sensor networks is driven by the current technologies, which guarantee the availability of low power consumption and low-cost devices. The most attractive standard for wireless sensor networks is the IEEE 802.15.4 standard, which provides low-rate and energy-efficient data transmissions. The network performance using common indicators, such as RSSI and PER are analyzed. Experimental results by measuring the received signal between nodes with a real IEEE 802.15.4 hardware are taken. All the experiments are conducted in an indoor environment, so that there are reflections due to walls and furniture. The relation between the RSSI and PER as a function of the distance are examined, and the collected experimental results are linearly interpolated.

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