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IR-UWB: An Ultra Low Power Consumption Wireless Communication Technologie for WSN

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Abstract

Wireless Sensor Network (WSN) has gained popularity in recent times in residential, commercial and industrial applications. Several wireless technologies have emerged ranging from short and medium distances. Bluetooth, ZigBee and Impulse Radio Ultra Wide Band (IR-UWB) are three short range wireless communications. There are several features of IR-UWB signals which make them attractive for a short range of wireless applications. Some of the major advantages of IR-UWB are low complexity, ultra low power consumption, and good time-domain resolution allowing for location and tracking applications. In this paper, we provide a performance study of these popular wireless communication technologies, evaluating the main features and advantages of IR-UWB for WSN in terms of the transmission time and power consumption. We used MiXiM platform under OMNet++ simulator to analyze and evaluate the main features of IR-UWB.

***Keywords**: WSN, Bluetooth, Zigbee, IR-UWB, Energy consumption, Transmission time*

1. Introduction

Wireless Sensor Network (WSN) is composed of a large number of cooperative sensor nodes, which are densely deployed either inside the phenomenon or very close to it, can communicate in broadcast fashion. The number of sensor nodes deployed in studying a phenomenon may be in the order of hundreds or thousands. Depending on the application, the number may reach an extreme value of millions. A sensor node is made up of four basic components namely sensing unit, processing unit, transceiver unit and power unit. Sensor networks may consist of different types of sensors. They are able to monitor a wide variety of ambient conditions such as temperature, vehicular movement, lightning condition, noise levels [1] have suggested that wireless sensors can be used where wired line systems cannot be deployed. The rapid deployment, self organization and fault-tolerance characteristics of WSNs make them versatile for military, medical, environmental, entertainment, transportation, crisis management and smart spaces.

Wireless sensor networks are intended to monitor events and phenomena in a specified environment [2] such as physical world, a biological system [3], or an information technology framework using autonomous [4] collection of sensor nodes with limited energy, storage and processing capabilities. While trying to send the monitored information to the base station or administrator to react to events and phenomena in specific environment congestion occurs. Generally sensors are deployed in large quantities with high density. So congestion is a likely event. Controlling congestion is difficult due to dynamically time varying wireless channel condition and contention caused due to interference by concurrence transmission and also traffic pattern in WSN is entirely different from traditional networks. In traditional networks destinations are random hence avoiding congestion is easy but WSN deliver myriad types of traffic ,its density increases when sudden event occurs and some nodes may worn out their battery power removal of such nodes in the network make uncongested part of the network become easily congested. This will degrade the network quality, increase the loss rate and unfairness toward nodes whose data has to traverse a large number of hops. Obviously, reducing the cable restriction is one of the benefits of wireless with respect to cabled devices.

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Other benefits include the dynamic network formation, low cost, and easy deployment. General speaking, the short-range wireless scene is currently held by three technologies are a wireless communication for Wireless Sensor Network: Bluetooth, ZigBee and IR-UWB.

The rest of this paper is organized as follows. In Section 2 we present the wireless communication technologies with a detailing of IR-UWB, the transmission time are presented in Section 3. Then in Section 4 we presented the energy consumption and lifetime; finally, Section 5 concludes the paper.

2. Wireless Communication Technologies

2.1. Bluetooth

Bluetooth is a Radio Frequency (RF) specification for short-range, point-to-point and point-to-multi-point voice and data transfer. Bluetooth will enable users to connect to a wide range of computing and telecommunications devices without the need for proprietary cables that often fall short in terms of ease-of-use. The technology represents an opportunity for the industry to deliver wireless solutions that are ubiquitous across a broad range of devices. The strength and direction of the underlying Bluetooth standard will ensure that all solutions meet stringent expectations for ease-of-use and interoperability [5]. The Bluetooth core specification contains both hardware and a software description. The former pertains to the lowest layers of the protocol stack, like the radio and the baseband, while the latter pertains to higher layers that are typically executed by dedicated microprocessors and/or the processor of a host device. These components are illustrated in Figure 1:

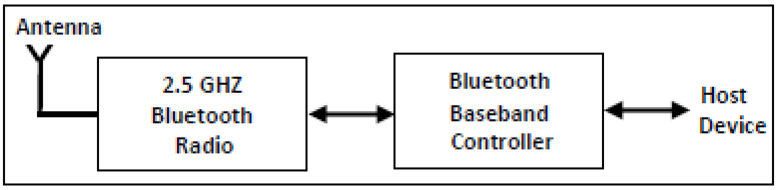

Figure 1. Bluetooth Components

Figure 2 depicts the Bluetooth protocol stack [6], which also shows the application and profiles “layer” for completeness. The Radio layer defines the requirements for a Bluetooth transceiver operating in the 2.5GH. In order to make different hardware implementations compatible, Bluetooth devices use the Host Controller Interface (HCI) as a common interface between the Bluetooth host and the Bluetooth core. Higher-level protocols like the Service Discovery Protocol (SDP), RFCOMM (emulating a serial port connection) and the Telephony Control Protocol (TCS) are interfaced to base-band services via the Logical Link Control and Adaptation Protocol. Among the issues L2CAP takes care of, is segmentation and reassembly to allow larger data packets to be carried over a Bluetooth baseband connection. The Service Discovery Protocol allows applications to find out about available services and their characteristics when, e.g. devices are moved or switched off.

Service Discovery Protocol (SDP), in specific, allows the users with Bluetooth devices to connect to the neighboring devices in a wireless manner. One notable characteristic about the SDP about the Service Discovery Protocol is its capability to enable Bluetooth wireless device users to get on-demand services. On July, 2000, the Bluetooth Special Interest Group (SIG) defined a process that enables system developers to employ the Saluation architecture for service discovery a utilization functions in Bluetooth short-range radio frequency (RF) networks. Further, SIG is developing new Bluetooth requirements, including Saluation and universal plug and play, to describe how to use other service discovery technologies in the Bluetooth environment. It is the authors’ belief that service discovery architecture eventually will come into prominence with the popularity of mobile commerce technology.

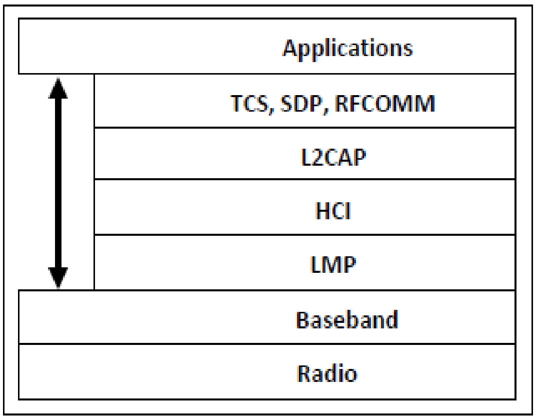

Figure 2. The Bluetooth Protocol Stack

2.2. Zigbee

Zigbee [7] defines two modes of operation: beacon enabled and non beacon enabled. In the former, a coordinator, called the Piconet Coordinator (PNC) sends periodic beacons. Beacons are followed by a so-called Contention Access Period (CAP), during which all nodes can compete independently for channel access using a CSMA/CA algorithm, and by a Collision Free Period (CFP), during which nodes communicate during time slots exclusively allocated by the PNC. In the non beacon enabled mode, nodes use a CSMA/CA protocol in their communication. ZigBee Alliance [8] defined the protocol stack upper layers.

The introduction of an IR-UWB made this protocol unable to operate, since it relies on CCA (in both of its modes). Therefore, adaptations were defined in the standard. In particular, the CSMA/CA mode is replaced by an ALOHA mode that does not rely on CCA. The MAC sub-layer handles all access to the physical radio channel. It provides an interface between the service specific convergence sub-layer (SSCS) and the PHY layer.

2.2.1. Network Components

In Zigbee network generally we can define three types of nodes [9]. These nodes are:

PAN coordinator: There can be only one coordinator for each ZigBee network. This node is liable for initializing the network, selecting the suitable channel and allowing other devices to connect to its network.

Full Function Devise: It can serve as the coordinator of a personal area network just as it may function as a common node. It implements a general model of communication which allows it to talk to any other device.

Reduced Function Devise: These nodes are only used to talk either a router or a coordinator. An end device connected to the network through either a router, or directly to the coordinator. There are three different types of topologies possible for a ZigBee network.

2.2.2. Network Topology

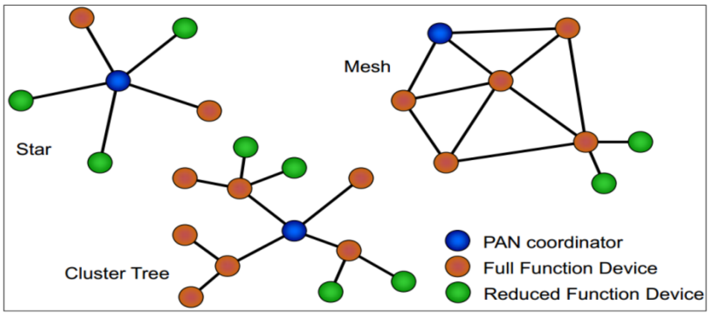

Figure 3. Zigbee Network Topology

As depicted in Figure 3, the basic network topologies supported by the network layer are star, mesh, cluster or three. In star topology devices have to first send a message to the PAN coordinator (PC) in order to communicate with each other.

Devices can directly communicate with each other without the intervention of PAN coordinator in mesh network topology. Cluster topology shares the features of both star and mesh topology [10].

2.3. IR-UWB

IR-UWB is a promising technology to address Wireless Sensor Network constraints. However, existing network simulation tools do not provide a complete WSN simulation architecture, with the IR-UWB specificities at the Physical (PHY) and the Medium Access Control (MAC) layers.

The IR-UWB signal uses pulses baseband a very short period of time of the order of a few hundred picoseconds. These signals have a frequency response of nearly zero hertz to several GHz. According to [11] there is no standardization, the waveform is not limited, but its features are limited by the FCC mask. There are different modulation schemes baseband for IR-UWB [12]. This paper uses the PPM technique for IR-UWB receiver.

2.3.1 IR-UWB Signal Information

IR-UWB signals are transmitted in form of very short pulses with low duty cycle (see Figure 4).

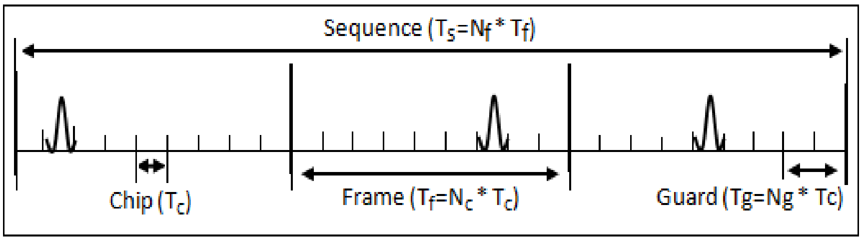

Figure 4. Classic IR-UWB signal [1] and its parameters: Tc is the duration of a chip, Tf = Nc.Tc is the duration of a frame and Ts = Nf.Tf is the duration of a sequence. Tg = Ng.Tc is guard

IR-UWB is a promising technology to address Wireless Sensor Network constraints. However, existing network simulation tools do not provide a complete WSN simulation architecture, with the IR-UWB specificities at the physical (PHY) and the Medium Access Control (MAC) layers.

The medium is divided into frames and each frame is shared in N_h chips. The frame and chip duration are T_f and T_c, respectively. The transmitted symbol can be repeated following a pseudo random sequence to avoid catastrophic collision under multiuser access conditions [13]. The kth user transmitted signal $S_{tx}^{(k)}(t)$ can be expressed as:

$$S_{tx}^{(k)}(t) = \sum_{j=-\infty}^{+\infty} \sqrt{E_{tx}} x_{tx}\left(t - j.T_f - c_j^k.T_c\right)$$

Where E_{tx} is the transmitted pulse energy; $t_{tx}(t)$denotesthe basic pulse shape and $\{c_j^k\}$ represents the jth component of the pseudo random Time Hopping Sequence. The received signal $r(t)$ when only one user is present can be expressed as:

$$r(t) = A.s_{tx}(t-\tau) + n(t)$$

$$r(t) = \sum_{j=-\infty}^{+\infty} A.\sqrt{E_{tx}} x_{tx}\left(t - j.T_f - c_j^k.T_c - \tau\right) + n(t)$$

Where τ represents the pulse propagation delay and $n(t)$ is Additive White Gaussian Noise (AWGN) with $\frac{N_0}{2}$ power density and A represents the signal attenuation observed during propagation [14]. It depends on the considered channel model in terms of path loss, multipath, shadowing. In a multi user scenario where N_u users are active, the received signal is expressed as:

$$r(t) = \sum_{k=1}^{k=N_u} A_k . s_{tx}(t - \tau_k) + n(t)$$

$$r(t) = A_1 . s_{tx}(t - \tau_1) + \sum_{k=2}^{N_u} A_k . s_{tx}(t - \tau_k) + n(t)$$

Where τ_k represents the delay associated to the propagation and a synchronism between clocks [13]. A_k represents the attenuation of the kth user's signal (k=1 represents the signal of the user interest). This formulation can be used to characterize the TH-IR-UWB PHY layer in a multi user scenario; however the used propagation delay does not represent the real propagation delay for the real deployment configuration. The used Bit Error Rate (BER) versus the Signal to Interference and Noise Ratio (SINR) is also based on a perfect power control assumption which is not always realistic.

2.3.2 Radio State Machine

Since the power consumption is derived from the time spent in each of the radio modes, it is important to model these accurately. The finite state machine illustrated in Figure 5 is used, with three steady states *Sleep*, *Rx* and *Tx*, and four transient states *SetupRx*, *SetupTx*, *SwitchRxTx* and *SwitchTxRx*. The radio can always leave any state (steady or transient) and immediately enter sleep mode.

The time spent in a transient state is a constant $T_{TrState}$, the power consumption in each state is P_{State} and the energy cost of a transition from one steady state to another is $E_{TrState}$.

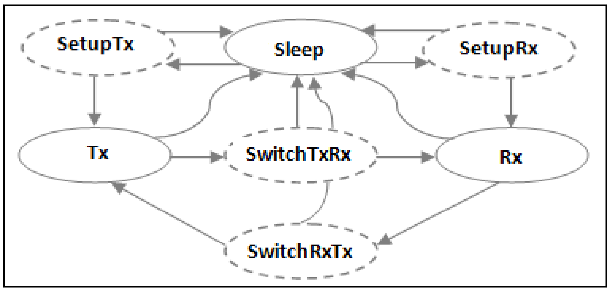

Figure 5. Detailed Radio Model Including Transient States

3. Transmission Time

The transmission time depends on the data rate, the message size, and the distance between two nodes. The formula for transmission time (μs) can be described as [15]:

$$T_{tx} = \left(N_{data} + \left(\frac{N_{data}}{N_{maxpld}} \times N_{ovhd} \right) \right) \times T_{bit} + T_{prop}$$

Where N_{data} is the data size, N_{maxpld} is the maximum payload size, N_{ovhd} is the overhead size, T_{bit} is the bit time, and T_{prop} is the propagation time between any two devices. For simplicity, the propagation time is negligible in this paper. The typical parameters of the three technologies used for transmission time evaluation are listed in Table 1. As shown in Figure 6, the transmission time for the ZigBee is longer than the others because of the lower data rate, while IR-UWB requires less transmission time compared with the others. Obviously, the result also shows the required transmission time is proportional to the data payload size and disproportional to the maximum data rate.

Table 1. Typical System Parameters

	Bluetooth	ZigBee	IR-UWB
Max data rate(Mbit/s)	0.72	0.25	100
Bit time (μs)	1.39	4	0.009
Max data payload (bytes)	339	102	2044
Max overhead (bytes)	158	31	42

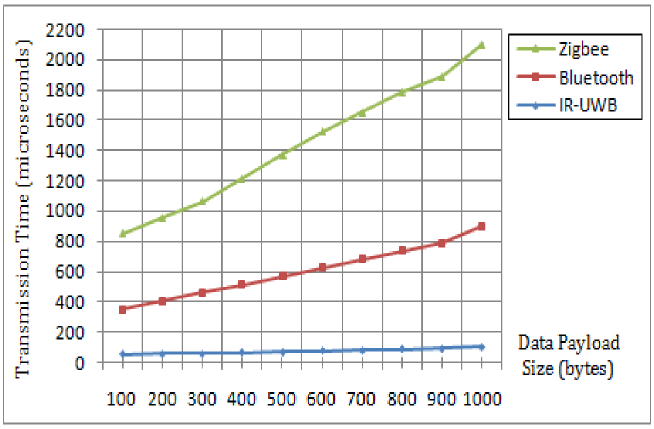

Figure 6. Transmission Time Versus The Data Payload Size

4. Energy Consumption and Life Time

4.1. Energy Consumption

In IR-UWB based WSN, devices communicate using the packet format illustrated in Figure 7. It consists of three components: synchronization preamble (SP), PHY-header (PHR), and payload. The very short duration of the pulses makes them difficult to detect. Since there is no carrier signal, the channel is empty most of the time even though a transmission is ongoing. The only part of the signal that can be reliably detected (using a dedicated algorithm) is the synchronization preamble, with which all transmissions begin. It consists of a deterministic sequence of isolated pulses used by all devices that are part of the same network (two synchronization preambles are defined in the standard).

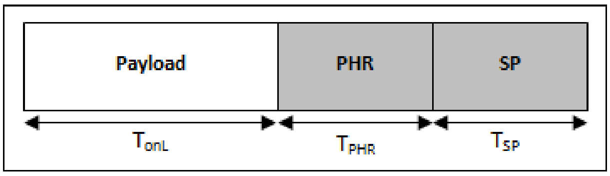

Figure 7. IR-UWB based WSN PHY Frame Format

The summation of energy consumption on delivering the SP and PHR (EO) with energy consumed on the payload (EL), is the energy consumption to transmit a packet [16].

The synchronization preamble has values {-1, 1} and is received coherently and PHR is modulated using DBPSK, always received coherently, and coded in the same manner as the payload. Therefore, the overhead energy consumption is:

$$E_O = E_O^{(TX)} + E_O^{(RX)}$$

$$= \left(L_{SP} + \frac{L_{PHR}}{R_c}\right) E_P + P_{SYN} T_O + P_{rx} T_O$$

Where,

$$T_O = T_{SP} + T_{PHR} = (L_{SP} + \frac{L_{PHR}}{R_c})/R_{base}$$

R_{base} is the fixed base data rate.

The energy consumption for the payload can be modeled as:

$$E_L = E_L^{(TX)} + E_L^{(RX)}$$

Where $E_L^{(TX)}$ and $E_L^{(RX)}$ represent the energy consumption to transmit/receive the payload containing L_L information bits, respectively.

$$E_L^{(TX)} = \frac{\rho_t E_P L_L}{R_c} + P_{SYN}$$

Where the time duration to transmit the payload containing L_L bits is $T_{onL} = L_L/R_b R_c$, and Rc is the coding rate. The energy consumption to receive L_L information bits is:

$$E_L^{(RX)} = \rho_t(MP_{COR} + P_{ADC} + P_{LNA} + P_{VGA})T_{onL} + \rho_r(P_{GEN} + P_{SYN})T_{onL}$$

T_{IPS} is the inter packet space (IPS). The power consumption during T_{IPS} is mainly due to the clock generator and synchronizer. Therefore, the corresponding energy consumption at the transmitter is $E_{IPS}^{(RX)} = P_{SYN}T_{IPS}$, while the receiver consumes $E_{IPS}^{(RX)} = \rho_r P_{SYN} T_{IPS}$. We assume that before transmission or reception of a packet, the transmitter and receiver spend $T_{tr} = 200\mu s$, to go from the off (sleep) state to an on (active) state. During this time period, the transmitter consumes $E_{tr}^{(TX)} = P_{SYN}T_{tr}$ amount of energy to start the front end clock generator and synchronizer. Similarly, the receiver consumes $E_{tr}^{(TX)} = \rho_r P_{SYN} T_{tr}$. T_{on} is the time duration for the transmission of one packet. That is:

$$\begin{aligned} T_{on} &= T_{SP} + T_{PHR} + T_{onL} \\ &= (L_{SP} + \frac{L_{PHR}}{R_c})/R_{base} + \frac{L_L}{R_b R_c} \end{aligned}$$

The energy consumptions at the transmitter and receiver during T_{on} are:

$$E^{(Tx)} = E_O^{(Tx)} + E_L^{(Tx)}$$

$$E^{(Rx)} = E_O^{(Rx)} + E_L^{(Rx)}$$

T_{ACK} is the time period when the transmitter listens for an acknowledgement. We set$T_{ACK} \approx T_O$. Overall, the definitions of the energy consumptions within one transmission are summarized as follows:

$$E_{IPS} = 2E_{IPS}^{(TX)} + 2E_{IPS}^{(RX)},$$

$$E_{LN} = \rho_r P_{SYN} T_{ACK}$$

$$E_{TRAN} = 2E_{tr}^{(TX)} + 2E_{tr}^{(RX)}$$

$$E_{ACK}^{(RX)} = P_{rx} T_{ACK}$$

$$E_{ACK}^{(TX)} = (L_{SP} + L_{PHR}/R_c)E_p + P_{SYN} T_{ACK}$$

The effective average energy consumption per one successful delivery can be expressed as:

$$E = \left(E^{(TX)} + E^{(RX)} + E_{LN} + E_{IPS}\right)N - E_{LN} + E_{TRAN} + E_{ACK}^{(TX)} + E_{ACK}$$

The average number of transmissions/receptions required to successfully deliver one packet is N. The average numbers of transmissions $N = \frac{1}{(1-P_b)^{LL}}$ where P_b is the average bit error probability (BEP). The probability that a packet is received correctly is $(1 - P_b)^{LL}$

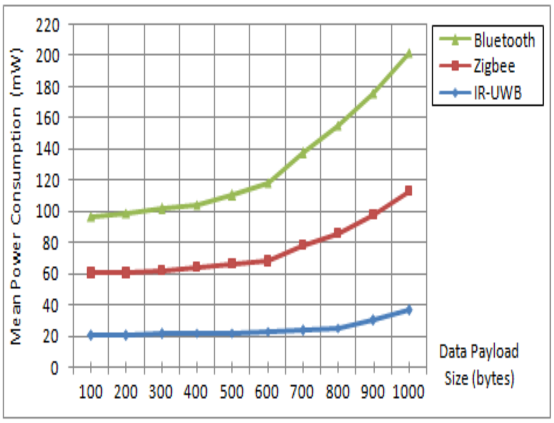

Figure 8. Nodes' Power Consumption Average

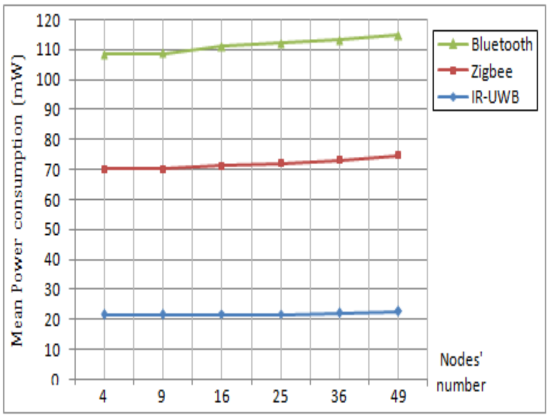

Figure 9. Nodes' Power Consumption Average

Energy was and is an interesting issue that is still a factor in the development of WSN. This factor affect directly the lifetime of the network. The low power consumption of the nodes network based on IR-UWB was concretized by the results shown in Figure 8 and Figure 9, varying respectively the data payload size and the nodes' number. They show that the power consumption by the WSN nodes based on IR-UWB is remarkably less than the case of Bluetooth and Zigbee. They show also that the value of power consumption inrcrese with increasing the data payload size as shown in Figure 8, and increasing the nodes number in the (see Figure 9). The result shown in Figure 9 is obtained by a data payload fixed at 512 bytes and varing the nodes' number.

4.2. Lifetime

Actually [17], the definition of the network lifetime depends on the application at hand. Indeed, it can be considered as:

a) The time until the first node fails (runs out of energy).
b) The time until the network is disconnected in two or more partitions.
c) The time until 50% of failed nodes.
d) The moment when the first time a point in the observed area is no longer covered by at least a sensor node.

In all these cases, the lifetime is strongly dependent on residual energy. Accordingly, we focus on the energy consumption of nodes to evaluate their lifetime and consequently network lifetime. In our model, we assume the following properties:

Based on [18], the energy cost Ci(t) of a node N_i at time t is the ratio of the total energy consumed at time t over the initial battery energy. It can be expressed as follows:

$$C_i(t) = \frac{Consumed_{Energy(t)}}{Initial_{Energy}}$$

Since energy levels are initially given with different values, we would like to normalize the Calculation of the energy cost in the interval [0, 1]:

a) $C_i(t)$ =0 means that the battery of the node *Ni* at time t is full.
b) $C_i(t)$ =1 means that the battery of the node *Ni* at time t is depleted.

If the energy cost of the greediest node in term of energy reaches the value 1 at time t, we note that its battery is exhausted and this moment represents the network lifetime:

$$Lifetime = \{t/max_{i\in network\_nodes}(C_i(t)) = 1\}$$

In what follows, we will present our analytical model to predict the network lifetime. First, we will give energy consumption basic equations. Second, to propose a more realistic analytical model, we will consider an unreliable network. Third, we will consider, in our analysis, the main sources of energy consumption, namely overheads, idle-listening and overhearing.

5. Conclusion

Wireless communication technologies emerge in the recent few years. They provide large opportunities in terms of low power consumption, high and low rate, and cost reduction. IR-UWB was mainly introduced in the field of WSN due to its various specificities and advantages, especially its low power consumption and low complexity advantages. In this paper we showed the impact and the gain brought by the use of this new technology in terms of energy consumption and transmission time compared to the Bluetooth and Zigbee. The good results in the case of the WSN based on IR-UWB are obtained due to the features and advantages of this new technology. We aim, as a future work, to develop a new adapted MAC and routing protocols that will be paired with this new technology.

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