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Energy Consumption Analysis of Single and Multihop Wireless Sensor Networks

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ABSTRACT— Wireless sensor networks are networks of devices with restrained resources, used for environmental, military, automation and home applications. Radio transceiver is one of the biggest power consumers in sensor node, so it's usage need to be very efficient in order to maximize node's operational life. Node can route it's messages towards destination either by using small or large hops. Theoretical knowledge favours using of smaller hops, known as multi-hop, which is considered as more efficient than single-hop. Optimizing the length of these hops may save energy, and therefore extend the lifetime of WSNs. This paper shows that single-hop transmission is more efficient, when power consumption of real wireless sensor node's transceivers are taken into account.

***Keywords* — single-hop, multi-hop, wireless sensor networks, energy efficiency**

INTRODUCTION

In the last two decades, development in Micro-Electro-Mechanical Systems technology, electronics and wireless communications has permitted the development of wireless sensor nodes that are small in size, cheap and communicate via multi-hops scheme. These sensors, also known as motes, are generally composed of a power source (battery), a processing unit with limited capacity and a communication component (transceiver)[1]. The deployment of these sensor nodes for the monitoring or the event detection in unattainable environment is known under wireless sensor networks (WSNs).In the last years, WSNs have been used in many applications like military surveillance ,disaster management, forest fire detection, seismic detection , habitat monitoring, biomedical health monitoring , home applications.

A sensor network is composed of large number of sensor nodes, which is randomly deployed in large area. In the most case, it is infeasible to replace or change the node batteries according to the nature of the monitoring area; therefore each node has strict limitations in the usage of its electrical power, computation and memory resources[2]. A sensor network should be very well-formed to achieve its purposes and to extend its life-time. Indeed how well the network is formed determines the life of the whole network as well as the quality of data transmission. The nodes batteries in a WSN are considered as scarce resources and should be used efficiently, because of the random deployment of nodes, with limited batteries power, in difficult terrains. A sensor node consumes its battery power in sensing, receiving, sending and processing data; therefore the most energy-consuming component is the radio module that provides wireless communications, indeed, sending/receiving data consumes more energy than any other operation. Therefore, the energy efficiency of the communication protocol designed for WSN, affects largely the energy consumption and network life-time of wireless sensor networks [3,4].

In the most times, sensor nodes in WSN do not have the necessary power and a sufficient communication range to reach the base station. So, the multi-hops mode of communication is used to forward data. In nowadays, sensors are equipped with developed radio transceivers, which have the possibility to adjusttheir transmitting power, so some destinations can be reached with either a large number of smaller hops (multi-hops) or a small number of larger hops (single-hop). The confusion over the required number of hops comes from the reality that each protocol (long-hops andshort-hops routing) has its own advantages. Transmitting data over many short-hops minimizes the transmissionenergy which is proportional with the communication distance. However, transmitting data over long distancereduces the reception cost (as the number of nodes involved in data routing decreases)[5].

Energy efficiency of these two approaches depends on: (i) path loss between transmitter and receiver (ii) power consumption of the radio transceiver in various operating modes[6]. It is theoretical known from state of the art that multi-hop routing is more efficient then single-hop routing. This is in an opposite to observations in some real world WSN, which shows that single-hop routing, can be much more energy efficient then multi-hop routing. Besides energy efficiency, single-hop routing can also have advantages for other network parameters, such as end-to end delay, lower packet loss, etc.

Radio channel between transmitter and receiver can be established only when strength of the received radio signal is grater then receiver's sensitivity threshold. The reduction in signal power density, on the path between transmitter and receiver, is called path loss[7]. Realistic path loss modeling can be a very complex task because transmitted radio waves could be reflected, absorbed or scattered by the obstacles. Receivers in a real environment receive not one but many delayed components of the original signal. Such phenomenon is called multipath fading.

OVERVIEW OF WSN TRANSCEIVERS

WSN nodes usually use transceivers, which operate in 2.4 GHz band, compliant to IEEE 802.15.4 standard. We can see that power consumption while transceiver receiving is higher than transmission at full power. Furthermore, energy efficiency of transmitting stage is very low (less than 2 % at full power). Energy efficiency decrease, as we lower transmission power, because many parts of a transceiver have constant energy consumption, no matter of transmission power. Typical radio range of these transceivers is usually about 100m outdoor and 30 m indoor. Range can be increased using analog front ends which increase transceivers' transmitting power as well decrease transceiver's sensitivity threshold.

THEORETICAL ANALYSIS

The simplest path-loss model, called free-space, assumes that there are no obstructions between transmitter and receiver. Other models take into account effects of multipath fading and one of the most commonly used is log-distance path loss model.

$P_L = \left(\frac{1}{d}\right)^{\alpha}$ (1)

This model employs path loss exponent α which is emirically measured under different propagation scenarios.
Using this model we can express receiving power P_r at distance d from the transmitter:

$$P_r = P_0 \left(\frac{d_0}{d}\right)^{\alpha} \quad (2)$$

Where P_0 represents known received power at distance d_0 from a transmitter and α is the path loss exponent. Pure theoretical model of wireless transmission, assumes that all consumed energy is radiated into the air by a transmitter, and a receiver doesn't spend any energy during a reception. Topologies of various types of single-hop and multi-hop communication are presented in Figure 1.

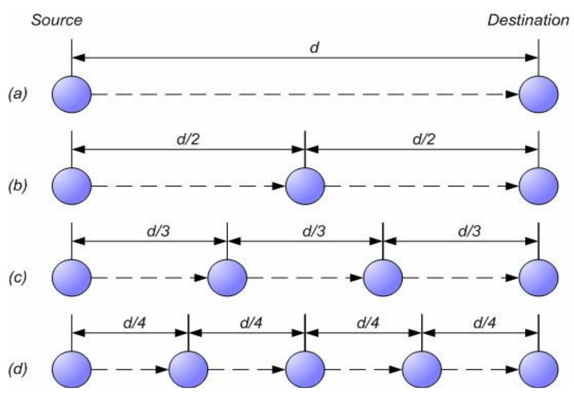

Fig1: Transmission distances for: (a) single-hop, (b) double-hop, (c) triple-hop, (d) quad-hop.

If we assume that transmitter, in single-hop scenario, emits at such as power P_1 which is just enough to be received by destination node, we can address this power as receiver's sensitivity threshold P_M

$$P_M = P_1 \left(\frac{d_0}{d}\right)^{\alpha} \quad (3)$$

In case of the double-hop, triple-hop, quad-hop P_1, P_2, P_3, P_4 ... P_n and n hop necessary transmitting powers will be:

$$P_M = P_2 \left(\frac{d_0}{d/2}\right)^{\alpha} \quad (4)$$

$$P_M = P_3 \left(\frac{d_0}{d/3}\right)^{\alpha} \quad (5)$$

$$P_M = P_4 \left(\frac{d_0}{d/4}\right)^{\alpha} (6)$$

$$P_M = P_n \left(\frac{d_0}{d/n}\right)^{\alpha} (7)$$

From using Equation (3) to (7), we get

$$P_1 = P_2.2^{\alpha} = P_3.3^{\alpha} = \dots = P_n.n^{\alpha} \quad (13)$$

Over all transmitter's power consumption used for single-hop, double-hop, triple-hop and n-hop will be:

$$P_{1h} = P_1 \quad (8)$$

$$P_{2h} = P_2 + P_2 = 2.\frac{P_1}{2^{\alpha}} (9)$$

$$P_{3h} = P_3 + P_3 + P_3 = 3.\frac{P_3}{3^{\alpha}} (10)$$

$$P_{nh} = n.\frac{P_1}{n^{\alpha}} (11)$$

We can clearly see that for any value of the path loss exponent greater than one, multi-hop transmission will be more energy efficient than single-hop transmission. If we assume that receiver is not ideal and for its work requires power P_R ,equations will get following form:

$$P_{1h} = P_1 + P_R \quad (12)$$

$$P_{2h} = 2.\frac{P_1}{2^{\alpha}} + P_R \quad (13)$$

$$P_{3h} = 3.\frac{P_3}{3^{\alpha}} + P_R \quad (14)$$

$$P_{nh} = n.\frac{P_1}{n^{\alpha}} + P_R \quad (15)$$

From this equations follows that multi-hop communication will be more efficient than single-hop only if received power consumption is:

$$P_R < \frac{n^{\alpha-1}-1}{(n-1)n^{\alpha-1}} P_1 (16)$$

We can conclude that primary condition for energy efficient multi-hop transmission is that receiver's power consumption must be small enough in comparison to transmitter's power consumption, required to achieve single-hop.

SIMULATION RESULTS

In Fig 2 , It's clearly that single-hop transmission is the most energy efficient than multihop transmission matter of path loss exponent. This can be explained because reception power for transceiver is much higher than maximum transmitting power. Also, single-hop has smaller power consumption because radio transmitter is more efficient at higher transmitting powers than lower

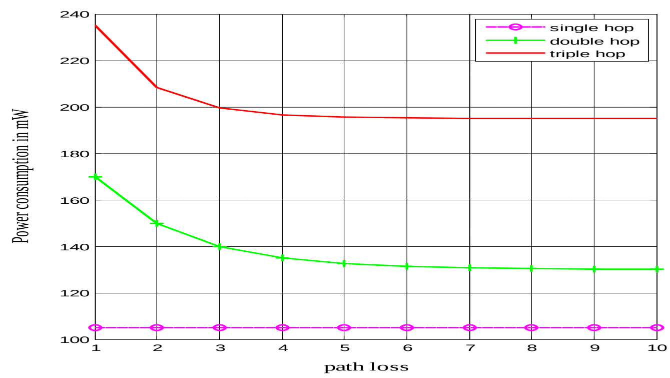

Fig2:The energy consumption with respect to path for single hop, double hop and triple hop communication

CONCLUSION

Results from simulations show that single-hop routing is much more energy efficient than multi-hop routing, using real worldtransceivers.Besides energy efficiency, single-hop routing can also have advantages for other network parameters. Future work will be concentrated into development of mathematical model, which will more precisely model power consumption of real WSN transceivers, so that model can be employed in some of the routing strategies

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