Short-hops vs. Long-hops - Energy efficiency analysis in Wireless Sensor Networks.

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***Abstract*—Sensor networks consist of miniaturized wireless sensor nodes with limited capacity and energy source. As sensors may be deployed in a large area, radio transceivers are the most energy consumer in sensor nodes, so their usage need to be very efficient in order to maximize network's life. A node can route it's messages towards destination either by using small or large hops, so optimizing the hop length can extend significantly the lifetime of the network. This paper provides a simple condition, to verify, which makes the energy consumption minimal by choosing ideal hop's length.**

***Keywords*-Wireless Sensor Network;Energy Efficiency;Multi-hop Routing;Hop Length; network's life;**

I. INTRODUCTION

Recent development in Micro-Electro-Mechanical Systems (*MEMS*) technology, wireless communications and digital electronics have allowed the devellopement of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short and long distances. 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], [2].The deployment of sensor nodes for the monitoring/detection of different events in environment is known as Wireless Sensor Network (*WSN*).

in these last years, WSN's have been used in many applications like military surveillance [3], disaster management [4], forest fire detection, seismic detection [5], habitat monitoring, biomedical health monitoring [6], inventory tracking, animal tracking, hazardous environment sensing and smart spaces, general engineering, commercial applications, home applications, Indeed, Business 2.0 [7] lists sensors as one of six technologies that will change the world, and Technology Review at MIT and Globalfuture [8] identify WSNs as one of the 10 emerging technologies that will change the world [9].

A sensor networks is composed of hundreds to myriads of sensor nodes, which appear to be deployed randomly by a car or airplane. Each node has strict limitation in the usage of it's electric power, computation and memory resources. They typically utilize intermittent wireless communication. Therefore, sensor networks should be well-formed to achieve its purposes, indeed how well the network is formed determines the life of the whole network as well as the quality of data transmission, also to reduce channel contention.

Senor nodes are endowed by a limited battery power and random deployment in difficult terrain ; make it almost impossible to recharge or to replace the dead battery. So, battery power in WSN is considered as scarce resource and should be used efficiently. Sensor node consumes battery in sensing data, receiving data, sending data and processing data. The most energy-consuming component is the R/F module that provides wireless communications [10]. Consequently, Out of all sensor node operation, sending/receiving data consumes more energy than any other operation. The energy consumption when transmitting 1 bit of data on the wireless channel is similar to energy required to execute thousands of cycles of CPU instructions [11]. Therefore, the energy efficiency of the wireless communication protocol largely affects the energy consumption and network lifetime of wireless sensor networks.

In the most times, sensor nodes in WSN do not have power and communication range to directly send the message to the base station. So, the multi-hops mode of communication is used to forward data[10]. Hence, a typical sensor node would not only sense and forwards its own data but also have to act as router i.e. forward the data of its neighbors. As far as sensor node operations are concerned sending/receiving data consumes more energy than any other operation. It can be inferred that data gathering and routing is one of the core area in WSN, where good protocols should be developed in order to achieve maximum energy efficiency.

All modern radio transceivers could adjust their transmitting power [12], so some destination could be reach with either large number of smaller hops (multi-hop) or small number of larger hops (single-hop). Energy efficiency of these two approaches depends on:

- path loss between transmitter and receiver,
- power consumption of the radio transceiver in various operating modes.

The debate over the number of required hops comes from the fact that each strategy (long-hops and short-hops routing) has its own advantages. Routing over many short hops minimizes the transmission energy which increases with the communication distance. However, sending packets over long distance relays reduces the reception cost (as the number of nodes involved in data routing decreases).

II. RELATED WORKS

The issue of routing packets over long-hops or short-hops has been treated by many authors in recent years and their conclusions are varied depending on the criteria considered and the approach taken [13].

Some theoretical works [14], [13] shows that multi-hop routing is more efficient than 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 than multi-hop routing [15], [16]. Besides energy efficiency, single-hop routing can also have advantages for other network parameters, such as end-to-end delay, lower packet loss, etc [12].

Yin et al. [17] presented two strategy of control, one of the methods consists of decreasing the transmission range of each node. According to the authors, this scheme will reduce the overall power consumption of the network, as a route with many short hops is generally more energy-efficient than one with a few long hops.

Haengi specified many reasons why long-hop routing is more advantageous [16]. One of them is the power efficiency. The author claimed that although the transmitted energy drops significantly with distance, the reduction of radiated power does not yield a decrease in the total energy consumption.

In this paper, we provide the optimal length for hops that make energy consumption optimal. For this we need to use the model, of the energy consumption, defined for the wireless sensor networks.

III. PROPAGATION MODEL

Radio channel between transmitter and receiver can be established only when strength of the received radio signal is greater than receiver's sensitivity threshold [12]. The reduction in signal power density, on the path between transmitter and receiver, is called path loss. In our study we use the log-distance path loss model, so the power received by a node distant of d meters from the sender can be expressed as follows [12], [13], [18]:

$$P(d) = P_0 \times \left(\frac{d_0}{d}\right)^{\alpha} \tag{1}$$

where P_0 represents the power of the signal received at distance d_0 from a transmitter and α is the path loss exponent, which is empirically measured under different propagation scenarios [18], [13]. Typical values of path loss exponent in such scenarios are presented in Table I.

Environment	α
Free-space	2
Urban area LOS	2,7 to 3,5
Urban area no LOS	3 to 5
Indoor LOS	1,6 to 1,8
Factories no LOS	2 to 3
Buildings no LOS	4 to 6

Table I
TYPICAL VALUES OF PATH LOSS EXPONENT

We use eq.1 to express the minimum power required to communicate over a given distance and we compare the two routing strategies (long-hop and short-hop routing). Every node is transmitting with the minimum power, required to guarantee the signal at the receiver, is equal to the sensitivity threshold P_t of the receiver [14], [13]. According to the figure 1 we can therefore write:

$$P_t = P_x \times \left(\frac{d_0}{x}\right)^{\alpha} \tag{2}$$

From which, we can get the energy required to reach the destination :

$$P_x = P_t \times \left(\frac{x}{d_0}\right)^{\alpha} \tag{3}$$

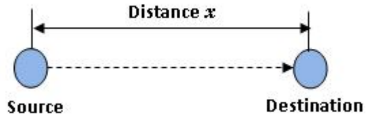

Figure 1. Transmission distance for one hop

In some pure theoretical model of wireless transmission, authors assume that all consumed energy is radiated into the air by a transmitter, and a receiver doesn't spend any energy during a reception [12]. According to them, if we consider only the total power transmitted over the path, then the short-hop strategy would be the most energy efficient, but since the reception cost should not be neglected [14], [10], [19], we will show in this paper that the use of long-hop strategy between two nodes (source and destination)is an optimal alternative. This is due to the fact that the savings in transmission power by the multi-hop scheme does not compensate for the resulting additional reception energy cost. The energy cost of the reception P_r can be equivalent to transmitting over a distant t [14]. Thus the formula:

$$P_r = P_t \times \left(\frac{t}{d_0}\right)^{\alpha} \tag{4}$$

IV. SHORT-HOPS VS. LONG-HOPS ANALYSIS

Figure 2 represents two topologies of multi-hop routing between two distant nodes, a source A and a destination B, with a distance d. The first topology uses n hops to transmit data from A to B (using short-hops of distance x); while the second uses m hops (using long-hops of distance y); with $n = 2 \times m$ ($y = 2x$), so wa can write :

$$P_t = P_x \times \left(\frac{d_0}{x}\right)^{\alpha} = P_y \times \left(\frac{d_0}{y}\right)^{\alpha} \tag{5}$$

Since $y = 2x$, eq.5 becomes :

$$P_y = P_x \times 2^{\alpha} \tag{6}$$

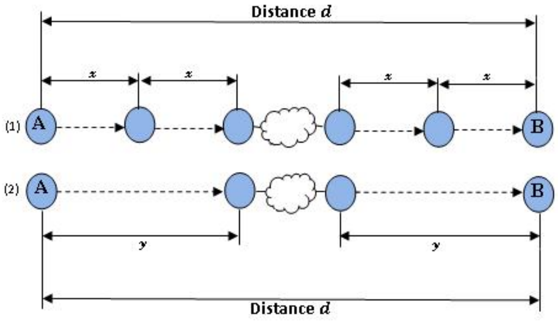

Figure 2. Transmission distance for : (1) n hops - (2) m hops

Using eq.3 and eq.4, we can now compute the energy required to transmit a message between A and B. For the first topology, we have a path with n hops. Thus we can express the power required to transmit data from A to B, usnig n hops, P_{nh}, as:

$$P_{nh} = \overbrace{(0P_r + P_x)}^{A} + \overbrace{(P_r + P_x) \ldots + (P_r + P_x)}^{(n-1)\text{ nodes}} + \overbrace{(P_r + 0P_x)}^{B}$$

And it can be expressed, also, as :

$$P_{nh} = nP_x + nP_r \tag{7}$$

Witch can be written as :

$$P_{nh} = 2m \times P_x + 2m \times P_r \tag{8}$$

We know from eq.6, that $P_x = \frac{P_y}{2^{\alpha}}$, therefore eq.8 becomes :

$$P_{nh} = m \times P_y \left[\frac{1}{2^{\alpha-1}} + 2\frac{Pr}{Py}\right] \tag{9}$$

With rhe same way, we can get the power required to transmit data from A to B, usnig m hops,

$$P_{mh} = mP_y + mP_r \tag{10}$$

Which equal to :

$$P_{mh} = m \times P_y \left[1 + \frac{P_r}{P_y}\right] \tag{11}$$

V. SHORT-HOPS VS. LONG-HOPS COMPARISON

In this section we present our main result. Lets compute, now, $P_{nh} - P_{mh}$:

$$P_{nh} - P_{mh} = m \times P_y \left[\frac{1}{2^{\alpha-1}} + 2\frac{Pr}{Py}\right] - m \times P_y \left[1 + \frac{P_r}{P_y}\right]$$

Which is equal to :

$$P_{nh} - P_{mh} = m \times P_y \left[\frac{1}{2^{\alpha-1}} - 1 + \frac{P_r}{P_y}\right] \tag{12}$$

$P_{nh} - P_{mh} > 0$ if and only if :

$$\frac{1}{2^{\alpha-1}} - 1 + \frac{P_r}{P_y} > 0 \tag{13}$$

Therefore :

$$\frac{P_r}{P_y} > 1 - \frac{1}{2^{\alpha-1}} \tag{14}$$

Which means :

$$y < \frac{t}{\sqrt[\alpha]{1 - \frac{1}{2^{\alpha-1}}}} \tag{15}$$

And since $y = 2x$, eq.15 becomes :

$$x < \frac{t}{2 \times \sqrt[\alpha]{1 - \frac{1}{2^{\alpha-1}}}} \tag{16}$$

And since $y > x$, inequalities 15 and 16 means that optimal energy consumption can be achieved when the length of the hops are included in the interval: $\left]\frac{t}{2\times\sqrt[\alpha]{1-\frac{1}{2^{\alpha-1}}}}\ ,\ \frac{t}{\sqrt[\alpha]{1-\frac{1}{2^{\alpha-1}}}}\right[$

VI. SIMULATION AND RESULTS VALIDATION

In this section, we perform the experiments with two sensor networks to verify the condition deduced from the theoretical analysis, one of these networks is composed of *Mica2* sensors and another composed of *Mica2dot* sensors.

In our simulation, we will use the experimental characteristics of these two sensors, so in order to evaluate the power consumed by *Mica2* and *Mica2dot* to transmit data from a node to an other, we will use the characteristics presented in [20] and described in table II:

	Mica2	***Mica2dot***
Reception	16 mA	12mA
Transmission	18 mA	14mA
Transmission range	55 m	135m
with maximum tx power	70m	230 m

Table II
EXPERIMENTAL CHARACTERISTIC OF MICA AND MICA2DOT MOTES

A. *First case study :*

To simulate the behavior of *Mica2* sensors, we assume that the networks are composed *Mica2* nodes which are aligned (*Transmitter-Relays-Sink*) with a length of 760 meters (distance between Transmitter and Sink), and we compute the energy consumed by these networks with different number of hops, which means different hop lengths, which means also, different number of relays, see figure 3.

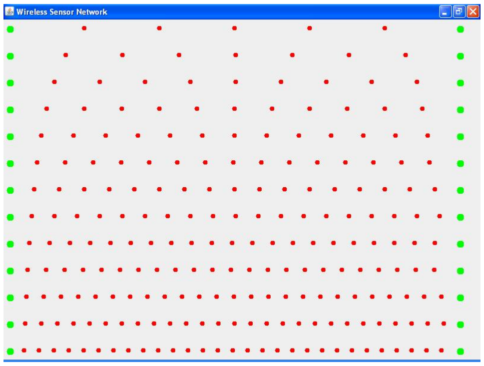

Figure 3. Networks of aligned sensors with different hops

computing the consumed power for these different aligned networks, with different hops length, gives the following results in table III :

Hops number	***Hop length*** m	***Total power consumed*** mA
6	126.6666	662.7732
8	95.0	557.59
10	76.0	503.672
11	69.0909	488.4290
12	63.3333	475.3866
14	54.2857	466.9028
16	47.5	466.2968
18	42.2222	476.9244
20	38.0	491.836
21	36.1904	499.6533
22	34.5454	503.3204
24	31.6666	521.2308
26	29.2307	546.1027
28	27.1428	569.4514
30	25.3333	591.5625

Table III
POWER CONSUMPTION VS HOPS LENGTH

We conclude from the table III, that the optimal number of hops that provide the minimum energy consumption is 16 hops (i.e hop length is 47.5 meter), which is verified by our condition that limits the length of hops that offer minimum energy consumption in : $]36.6678, 73.3357[$. For easier reading, we present the results in the figure 4:

B. *Second case study :*

With the same way, we simulate the behavior of *Mica2dot* sensors, we compute the consumed power for different aligned networks, with different hops length. we got the results in table IV

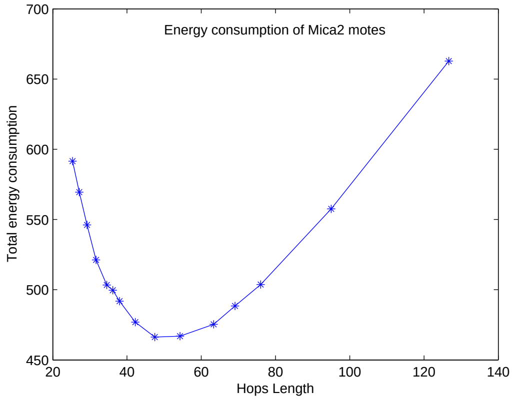

Figure 4. Mica2: Energy consumption Vs hops length

Hops number	***Hop length*** m	***Total power consumed*** mA
2	380.0	245.7984
4	190.0	158.8992
5	152.0	148.7193
6	126.6666	145.1566
8	95.0	151.4496
10	76.0	164.3596
11	69.0909	172.3269
12	63.3333	180.5783
14	54.2857	199.3528
16	47.5	219.1441
18	42.2222	240.3855
20	38.0	262.1798
22	34.5454	283.5317
24	31.6666	305.7131
26	29.2307	328.7930
28	27.1428	351.6764
30	25.3333	374.4000

Table IV
POWER CONSUMPTION VS HOPS LENGTH

From table IV we can get the number of hops, 6 hops (i.e length hop $= 126.6666$) , which makes the energy consumption minimum. This result is verified, also, by our condition that limit the length of hops that ensure the minimum energy consumption in $]88.3883, 176.7766[$. For easier reading, we present the results in the figure 5:

VII. CONCLUSION

We have analyzed the problem of hopping distance strategy in WSN and simulation results shows the impact of the choice of the length of hops. We showed, also, that the condition expressed in this paper, guarantee more energy efficiency, and help us to extend the network's life. Moreover, using the minimum hop length can be more efficient in the case of transmission failures that requires retransmission. In futures work we will focus on the problem of routing data by

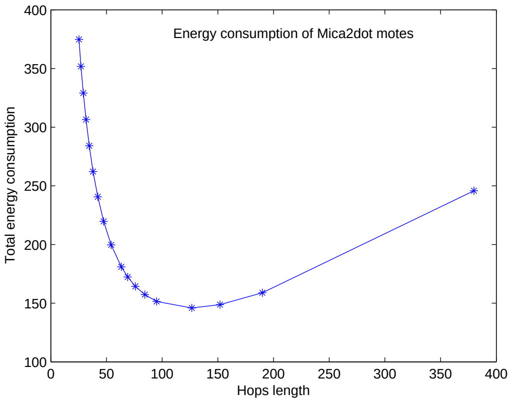

Figure 5. Mica2dot: Energy consumption Vs hops length

the less costly path in terms of energy, using the condition presented in this paper.

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