Duty-Cycle Impact at Lifetime of Wireless Sensor Networks

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Abstract— *in this paper we give some aspects of duty cycle technique, which can improve the efficiency and scalability of wireless sensor networks. The Wireless Sensor Network (WSN) is a network consisting of ten to thousand small nodes with sensing, computing and wireless communication capabilities. WSNs are generally used to monitor activities and report events, such as pollution parameters, healthcare issues,fire info etc. in a specific area or environment. It routs data back to the Base Station (BS). Data transmission is usually a multi-hop from node to node towards the BS. This type of networksis limited in power, computational and communication bandwidth. The main goal of all researchers is to find out the energy efficient method, which will improve considerably networks resources in term of prolonging lifetime of sensor nodes.*

In this paper, the lifetime of the node based on overall energy consumption is estimated and the effect of duty cycle on expected energy consumption is studied.Duty cycle is one of the used method, which plays an important role for saving energy in **WSNs**

Keywords— *WSN, Base Station,Protocol, Sensor, Node.*

I. INTRODUCTION

Wireless Sensor Networks (WSN) has beenmadeforenvironmental, health, military, agriculture monitoring etc. The main goal of a wireless sensor node is to sense and collect data from a certain location, process them and transmit it to the sink (base station) where the application lies. However, ensuring the direct communication between a sensor andthe sink may force nodes to emit their messages with such a high power that their resources could be quickly depleted. For this reason, the collaboration of nodes to ensure that distant nodes communicate with the sink is a requirement. In this way, intermediate nodes propagate messages so that a route with multiple links or hops to the sink is established. The lifetime of installed nodes at WSN is most challenge issue where many researchers have published many papers presentingdifferent methods for extending nodes lifetime.

Duty cycling is one of the basic and most commonly used power management techniques where a node is periodically placed into the sleep mode, which is an effective method of reducing energy dissipation in wireless sensor networks (WSNs) and in same time extending lifetime of sensor nodes [1].

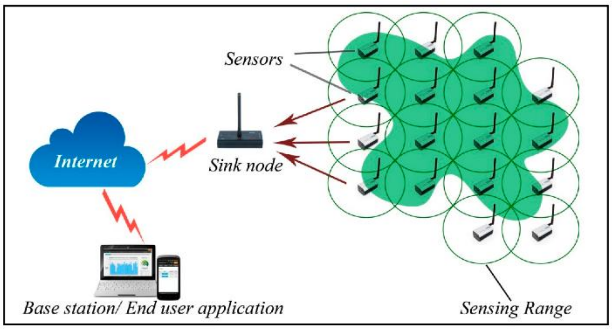


Fig. 1 Typical Multi-hop WSN Architecture

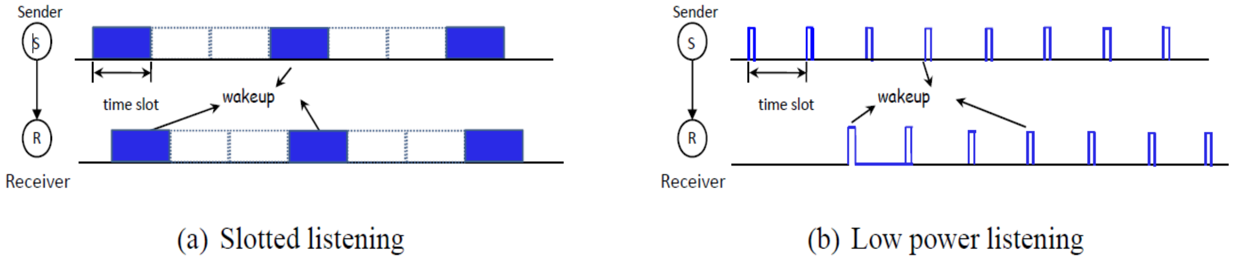
Many researchers havenoticed that idle energy plays an important role for saving energy in WSNs [2]. Most existing radios (i.e., CC2420 [3]) used in WSNs support different modes, such as transmit/receive mode, idle mode, and sleep mode. In the idle mode, the radio is not communicating but the radio circuitry is still turned on, resulting in energy consumption which is only slightly less than that in the transmitting or receiving states. Thus, a better way is to shut down the radio as much as possible in the idle mode [3].

The typical energy consumption parameters for a Telosb [10] listshown in Table I

TABLE I
Energy consumption of different components in Telosb

Module	Power	Remarks
Processor/memory	1.8 mA	Active mode
Processor/memory	5.1 µA	Sleep mode
Radio RX mode	18.8 mA	Receiving
Radio TX mode	17.4 mA	Transmission
Radio Idle mode	21 µA	
Radio Sleep mode	1 µA	

Considered time is arranged into consecutive and equal time slots. There is two modes for low duty cycle operation that can be identified: slotted listening mode [4, 5] and low power listening mode. In the slotted listening mode, as shown in Fig. 2(a), a node is wholly awake in select slots and asleep in the remaining slots when there is no data transmission or reception. In the low power listening (LPL) mode, as shown in Fig. 2(b), a node will be fractionally awake in every slot.



(a) Slotted listening

(b) Low power listening

Fig. 2 Duty-Cycle function

Definition of duty cycle can be as the percentage of time a node is active in the operational time. Generally, the duty cycle in the LPL mode is lower than that in the slotted listening mode.

Adaptive duty cycling has been proposed in the recent works on energy-harvesting technologies [5, 6], such as solar power to replenish battery supply in WSNs.

Because of high costs and the unavailability of a continuous power supply, it is not feasible to have instantly sufficient energy output. Hence, saving idle energy consumption is still necessary. Adaptive duty cycling is thus proposed to save energy consumption and to prolong the sustainable workable time per node.

The duty cycle setting can be based on the residual energy [7], node location, or the rechargeable energy [8] on each node, independently. Although low and adaptively duty-cycled operations can yield greater energy efficiency for WSNs, neighbour discovery becomes more complex than that in conventional works for always-on mechanisms (e.g., CSMA), since we cannot guarantee that two nodes are awake simultaneously.

On the other hand, for centralized algorithms, combining the messages that simultaneously go the central node (even when they are generated by different sources) could be an advantage. The distributed algorithms should efficiently support the communication between any two pairs of nodes.

Finally, local based algorithms depend on some solution that provides geographic coordinates, like GPS, making the solution more expensive.

II. RELATED WORK

As a rare resource for sensor networks, energy has to be managedsmartly in order to prolong the life of the sensor nodes for the duration of a particular activity. Manystudies have been done to reduce the power consumption and lifetime of wireless sensor networks. In general two main enabling techniques are identified i.e. duty cycling and data- driven approaches. Duty cycling [8] is the most effective energy-conserving operation in which whenever the communication is not required, the radio transceiver is located in the sleep mode.

In order to improve efficiency of installed network nodesdifferent algorithms and protocols has been released. Honghai Zhang et. al [5] designed an algorithm based on the derived upper bound, an algorithm that sub optimally schedules node activities to maximize the α-lifetime of a sensor network where the time is normalized to be the lifetime of each sensor node. In [9], the node locations and two upper bounds of the α-lifetime are allocated.

Based on the derived upper bound, an algorithm that sub optimally schedules node activities to maximize the α-lifetime of a sensor network is designed. Simulation the proposed algorithm achieves around 90%of the derived upper bound.

This implies that the derived upper bounds are rather tight and the proposed algorithm is close to optimal.

The energy consumption of WSN node is measured in different operational states, e.g., idle, listen, transmit and sleep. These results are used to predict the WSN node lifetime with variable duty cycle for sleep time.

It has been concluded that sleep current is an important parameter to predict the lifetime of WSN node. Almost 79.84% to 83.86% of total energy is consumed in sleep state. Minimization of WSN node sleep state current (Isleep)from 58μA to 8μA has shown improvement in lifetime by 188 days for the 3.3V, 130mAh battery.

It is alsodefined that the WSN node lifetime also depends on the packet size of data.

Data packet size is inversely proportional to the lifetime of the node. As data packet size is increased, the lifetime of the battery is decreased. Yuqun Zhang et. al [9] proposed an adaptation method for the derived distance-based duty cycle based on local observed traffic.

In this paper, the Packet Delivery Ratio (PDR) values are achieved by three methods.

It assigns different duty cycles for nodes at different distances from the base station to address the energy hole problem, improve network lifetime, and also to maintain network performance.

III.PROPOSED DESIGN

A. Estimation of Lifetime of the Node Based on Overall Energy Consumption.

In the today's work, the lifetime of the nodes isestimated by the overall energy consumption of the nodes such as in [10]. If the energy consumption decreases, lifetime of the node is increased. The total energy consumed by the nodes consists of the energy consumed for receiving (E_{rx}), transmitting (E_{tx}), listening for messages on the radio channel (E_{listen}), sampling data (E_d) and sleeping (E_{sleep}). The values and notations listed in Table I and Table II are used in this paper.

Total energy consumed is given by

$E = E_{rx} + E_{tx} + E_{listen} + E_{d} + E_{sleep}$ (1)

TABLE II

Parameters used for calculation

Notation	Parameter	Default
C_{sleep}	Sleep Current (mA)	0.025
C_{batt}	Capacity of battery (mAh)	1950
V	Voltage	2.5
$L_{preamble}$	Preamble length (bytes)	258
L_{packet}	Packet length (bytes)	31
t_i	Radio Sampling interval (s)	100E-3
R	Sample rate(packet/s)	1/285
L	Expected lifetime(s)	

TABLE IIII

Parameters used for calculation

Operation	Time (s)		I (mA)	
Initialize radio (b)	320E -6	$t_{r\ init}$	5	$c_{r\ init}$
Turn on radio (c)	1.5E -3	$t_{r\ on}$	1.5	$c_{r\ on}$
Switch to RX/TX(d)	220E-6	$t_{rx/tx}$	13	$c_{rx/tx}$
Time to sample radio (e)	310E -6	$t_{r\ sr}$	14	$c_{r\ sr}$
Evaluate radio sample (f)	105E -6	$t_{r\ ev}$	7	$c_{r\ ev}$
Receive one byte	390E -6	$t_{r\ xb}$	14	$c_{r\ xb}$
Transmit one byte	405E -6	$t_{t\ xb}$	22	$c_{t\ xb}$
Sample sensors	1.1	t_{data}	21	c_{data}

The energy associated with sampling data Ed, is

$E_d = t_d C_{data} V$ (2)

where $t_d = t_{data} \cdot r$ (3)

t_d being the time of sampling data, tdata is the sample sensors, r is the sample rate (packets/s), C_{data} is the current in sample sensors (mA), V is the voltage. The energy consumed for transmission (E_{tx}) is the length of the packet with the preamble times the packets rates and is given by

$E_{tx} = t_{tx} C_{txb} V$ (4)

where

$t_{tx} = r \cdot (L_{preamble} + L_{packet}) t_{txb}$ (5)

t_{tx} is the time to switch the transmitter, $L_{preamble}$ is the preamble length (bytes), L_{packet} is the packet length (bytes), t_{txb} is the time (s) to transmit 1 byte, C_{txb} is the current required transmitting 1 byte, V is the supply voltage.

The density of neighbors surrounding a node is referred to as the neighborhood size of the node. Receiving data from neighbors shortens a node's lifetime.

The total energy consumed by receiving data (E_{rx}) is given by

$E_{rx} = t_{rx} C_{rxb} V$ (6)

where, $t_{rx} <= nr(L_{preamble} + L_{packet}) t_{rxb}$ (7)

t_{rx} is the time (s) to switch the receiver n is the neighborhood size of the node, t_{rxb} is the time (s) to receive 1 byte, C_{rxb} is the current required to receive 1 byte.

In order to reliably receive packets, the low power listening (LPL) check interval, ti, must be less than the time of the preamble, i.e., $L_{preamble} \geq [t_i/t_{rxb}]$.

The power consumption of a single LPL radio sample is considered as 16.6μJ [11].

The total energy spent listening to the channel is the energy of a single channel sample times the channel sampling frequency.

E_{sample} =16.6µJ

$$t_{listen} = (t_{rinit} + t_{r\ on} + t_{rx}/t_x + t_{sr}) \cdot \frac{\mathbf{1}}{\boldsymbol{ti}} \quad (8)$$

$$E_{listen} \boldsymbol{<=} E_{sample} \cdot \frac{1}{t_i} \quad (9)$$

where, t_{rinit} is the initialize radio time, $t_{r\ on}$ is the turn in radio time, trx/tx is switch to rx/tx time, t_{sr} is the time to sample radio. The node must sleep for the rest of the time, so the sleep time t_{sleep} is given by

$$t_{sleep} = 1 - t_{rx} - t_{tx} - t_d - t_{listen} \quad (10)$$

and

$$E_{sleep} = t_{sleep}\ C_{sleep} \cdot V \quad (11)$$

The lifetime of the node (L) depends on the capacity of the battery (C_{batt}) and the total energy consumed by the battery (E) and given by

$$L = (C_{batt} \text{ x V})/E \quad (12)$$

The lifetime of the node is also dependent on the duty cycle (d) and the transmission energy (E_{Tx}), as the duty cycle increases the lifetime of the battery decreases.

Lifetime (in seconds) may be given as

$$L = \frac{(C_{batt}\ x\ 3600)}{(E_{tx}\ x\ d)}$$

B. *Impact of Duty Cycle on Expected Energy Consumption*

The traffic transmitted at a node is related to its distance to the sink, the number of source nodes in the network, the packet traffic generated by each source node and the node density. The time required for a transmission and the energy efficiency of the network is closely related to the duty cycle values used. Higher values of duty cycle provide more nodes available for data routing and thereby energy consumption of the nodes increases. In [12], a circle area is assumed with the sink located in the center and the nodes including the sources, which are uniformly randomly allocated with r_T as the transmission range.

The nth ring is defined as the ring whose inner circle is $(n-1)r_T$ away from the sink with widthr_T. Nn nodes are considered in such proposed ring. The average traffic that must be transmitted by all of the nodes located in the nth ring per unit time, Γn, is the summation of the traffic generated by the source nodes in the nth ring and within the rings outside of the nth ring per unit time, i.e.,

$$\Gamma_n = \lambda_g \rho_s \pi \{R^2 - [(n-1)r_T]^2\} \quad (13)$$

where λg is the average traffic generation rate of the source nodes, ρs is the density of source node, R is the radius of the network area,r_T is the transmission range. The traffic transmittedat a node is depended on the node distance from the sink, the node density, the radius of the network area, and the transmission range. The average traffic rate of a node at distance r, λr, is

$$\lambda_r = \frac{\lambda_g \rho_s \pi \{R^2 - [(\frac{r}{r_T} - 1)r_T]^2\}}{\rho_r \pi \{[\left\lceil \frac{r}{r_T} \right\rceil r_T]^2 - [(\left\lceil \frac{r}{r_T} \right\rceil - 1)r_T]^2\}} \quad (14)$$

Here, a constant power value P is supposed for idle listening, transmission, and reception. The expected total time for the complete RTS, CTS, DATA, and ACK packet communication is given by

$$t_c = t_{RTS} + xt_{CTS} + t_{data\,.} + t_{ACK} \quad (15)$$

The expected energy consumption P is defined as:

$$\bar{P} = P\{d + \lambda_T[(e^{\xi dN} - 1)^{-1} N_p N_r t_{CTL} + 2t_{data}\} \quad (16)$$

where P is the constant power, d is the duty cycle, λr is the average traffic rate of a node at distance r, ξ is the ratio of the transmitted region, N denote the average number of nodes within a node's transmission range, $t_{RTS} \approx t_{CTS} \approx t_{CTL} \approx t_{ACK}$ and it is the total expected time for a complete RTS, CTS, DATA and ACK packet communication.

The values used in calculation is listed in Table IV.

TABLE IIIV

Parameters used for calculation

Notation	**Parameter**	**Values**
Power	P	32E -6
Average traffic rate of the node	λ_T	0.15
Priority regions	N_p	3.5
CTS contention slots	N_p	4.1
Ratio of the relay region	ξ	0.35
Total expected time for transmission	t_{CTL}	1.5 * exp(-5)
Expected time for	t_{data}	1.25

transmission of data		

IV. EXPERIMENTAL SIMULATION RESULTS

In this research, we have estimated the lifetime of the battery sensor nodes and relation of energy consumption of the nodes on duty cycle. The computation is carried out using ORIGINPRO 8. The node's lifetime is determined by its overall energy consumption. If the lifetime is maximized, then the energy consumption is minimized. The lifetime of the sensor node is inversely proportional to the duty cycle. Figure 3 shows the relation between energy consumption and duty cycle. It is decided from the simulation results that for duty cycle, which is less than 0.01%, the energy consumed by the nodes decreases curvy linearly and for duty cycle beyond 0.01% the energy consumed by the sensor nodes increases linearly

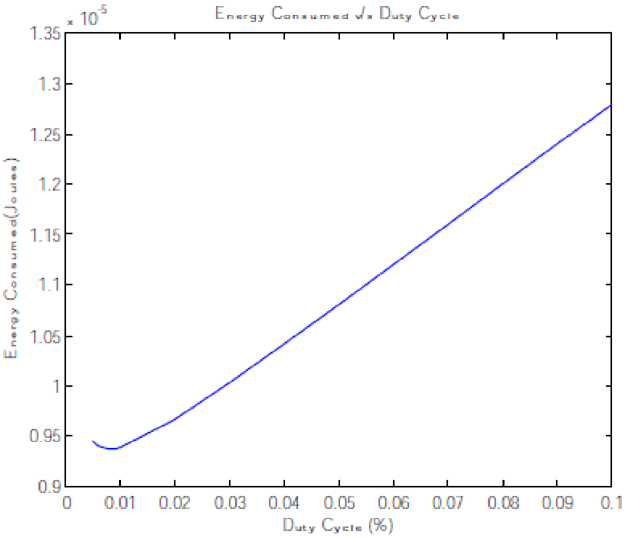


Fig.3 Energy consumed vs Duty cycle

Figure 4 shows the relation between lifetime of the node and the duty cycle (10%-100%) and it is concluded from the simulation result that as the duty cycle increases, the lifetime of the node decreases.

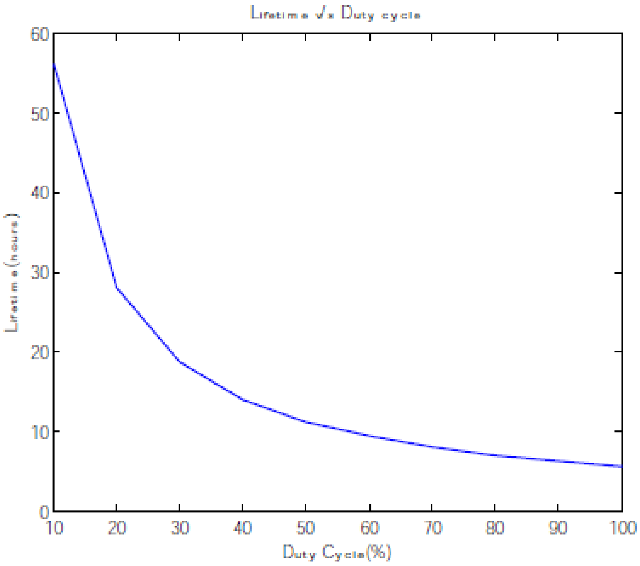


Fig.4 Lifetime vs Duty cycle

Increasing the duty cycle, the energy consumption of the nodes also increases, so for the optimum power management of the sensor nodes the duty cycle must be minimised.

V. CONCLUSIONS

In this paper, we reviewed several different operating strategies regarding energy consumption at wireless sensor networks. Therefore, such strategiesdesigned for WSN should be energy efficient as possible to prolong the lifetime of individual sensors.

Wireless Sensor Network technology extends numerousapplication domains and it is crucial that WSNs perform in reliable and robust manner. One of the major issuesin the design of different modules for WSN is energy efficiency due to limited energy resources of sensors.

The lifetime of the node based on overall energy consumption and effect of duty cycle on expected energy consumption areanalysed and estimated. Simulation results proved that for denser network, if the duty cycle is less than 0.01%, energy consumption decreases. Regarding other networks,it is correct for duty cycle value less than 0.02%. Otherwise, energy consumption increases with duty cycle. Therefore given proposed design help us in assigning a proper duty cycle value for WSNs.

Targetingto prolong network lifetime, above mentionideasimprove main parameter's that has big impact at energy consumption in wireless sensor networks.

REFERENCES

[1] Francesco Zorzi, Milica Stojanovic and Michele Zorzi, „On the Effects of Node Density and Duty Cycle on Energy Efficiency in Underwater Networks‟, Conference Europe, 2010

[2] Lin, J.; Liu, Y.; Ni, L.M. SIDA: Self-organized ID Assignment in Wireless Sensor Networks. In Proceedings of the 4th IEEE International Conference on Mobile Ad-hoc and Sensor Systems Conference (MASS), Pisa, Italy, October, 2007.

[3] Tokuya Inagaki and Susumu Ishihara, "HGAF: A power saving scheme for wireless sensor network", *Journal of Information Processing*, vol. 17, pp. 255-266, Oct. 2009.

[4] Joseph Polastre, Jason Hill, David Culler, „Versatile Low Power Media Access for Wireless Sensor Networks‟, November 3–5, 2004.

[5] Honghai Zhang and Jennifer C. Hou, Maximizing α-Life time for Wireless Sensor Networks, IJSNet1(1/2), 2006,pp.64-71..

[6] Braginsky, D.; Estrin, D. Rumor Routing Algorithm for Sensor Networks. In Proceedings of the First ACM International Workshop on Wireless Sensor Networks

and Applications (WSNA), Atlanta, GA, USA, September, 2002; pp. 22–31.

[7] Sadagopan, N.; Krishnamachari, B.; Helmy, A. The ACQUIRE Mechanism for Efficient Querying in Sensor Networks. In Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications (SNPA), Anchorage, AK, May, 2003; pp. 149–155.

[8] E. Y. A. Lin, J. M. Rabaey, and A. Wolisz, "Power-efficient Rendez-vous schemes for dense wireless sensor networks," *Proceedings of the IEEE International Conference on Communications*, pp. 3769–3776, June 2004.

[9] Yuqun Zhang, Chen-Hsiang Feng, Ilker Demirkol, Wendi Rabiner Heinzelman: Energy-Efficient Duty Cycle Assignment for Receiver-Based Convergecast in Wireless Sensor Networks, pp: 1-5.

[10] Seada, K.; Zuniga, M.; Helmy, A.; Krishnamachari, B. Energy-Efficient Forwarding Strategies for Geographic Routing in Lossy Wireless Sensor Networks. In Proceedings of the Second International Conference on Embedded Networked Sensor Systems, Baltimore, MD, USA, November, 2004; pp. 108–121.

[11] Curt Schurgers, Vlasios Tsiatsis, Saurabh Ganeriwal, Mani Srivastava,"Optimizing sensor networks in the energy-latency-density design space," IEEE Trans. on Mobile Computing, vol. 1, Jan-Mar 2002, p. 70-80.

[12] Fang, Q.; Gao, J.; Gubias, J. Locating and Bypassing Routing Holes in Sensor Networks. In Proceeding of the 23rd Conference of the IEEE Communications Society (INFOCOM), Hong Kong, China, March, 2004; pp. 2458–2468.

[13] Xu, Y.; Heidemann, J.; Estrin, D. Geography-informed Energy Conservation for Ad Hoc Routing. In Proceedings of the Seventh Annual International Conference on Mobile Computing and Networking (MOBICOM), Rome, Italy, July 2001; pp. 70–84.