Power Optimization in Wireless Sensor Network: A Perspective

Pankaj Chauhan, Tarun Kumar

***Abstract*— WSN refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. Procedure of the wireless sensor networks are sensing, actuating and relaying the collected information. Wireless Sensor Networks usually battery powered, and very energy constrained, present main challenge is the energy efficiency. Usually in WSNs the communication consumes most of the energy. But recently wireless sensor nodes are introduced that comprise also energy-consuming sensors, apart from normal ones like for temperature, pressure and humidity sensors. Therefore, besides the well explored power management techniques on the transceiver activity and wireless transmission, there is a necessity to instigate also the power management on the sensing unit that reduces the power consumption of the power-hungry sensors. This paper focuses on the introduction of wireless sensor network, node architecture, power issues regarding their routines, consumption of battery power in transmission and routing in MAC layer by various protocols and comparative analysis**

***Index Terms*— Micro-controller, Omni-directional antennas, power issue . WSN**

I. Introduction

Wireless Sensor Networks refers to highly distributed networks of small and lightweight wireless nodes with very limited capabilities, deployed in large numbers in an open environment to monitors the environmental conditions by measuring physical parameters such as temperature, pressure, humidity etc. Each node (sensor) has a microprocessor and a small amount of memory for sensing, signal processing and for communication purposes. Each sensor node communicates wirelessly with other local nodes within its radio communication range. Deployment of WSN's evade installation costs but at the same time power efficiency as a main challenge. A scheme of a wireless sensor node connected to the internet is shown in Fig. 1: Wireless sensor networks mainly consists of sensing unit, processing unit, transmission unit and power unit [2].

 Sensing unit: Sensing unit consists of a sensor and analog to digital converters (ADCs) which converts analog signal produced by sensor to digital signal. Sensoe converts physical phenomenon to electrical signal.

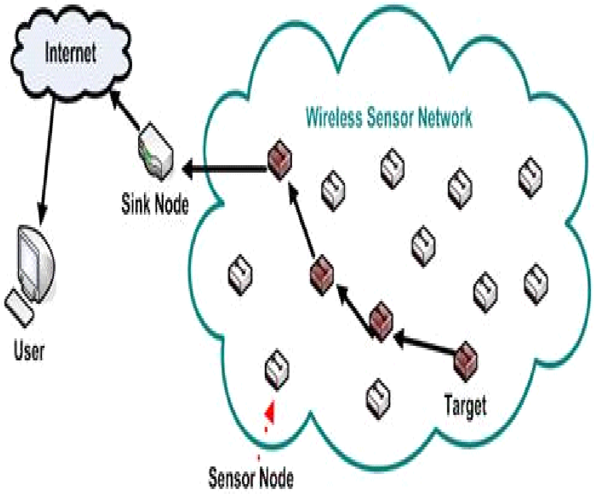

Fig. 1. Wireless Sensor Networks [1]

 Processing unit: The processing unit constitutes of a microprocessor or microcontroller which control sensors, execution of communication protocols and signal processing algorithms on the collected sensor data.

 Transmission unit: Transmission unit collects the information from the CPU and then transmit it to the end user in the outside world.

 Power unit: In wireless sensor network, the main source of energy is the battery power. So power unit supplies the battery power to sensor node.

1.1 WSN Overview and Node Architecture

In WSN, several nodes are deployed over an area to sense the physical parameters like pressure, temperature, humidity etc. and to forward the collected data to further network. Hence a typical sensor node must have sensing, processing and communication capabilities for this purpose. These sensors may be deployed to get the real-time data from the critical location, where wired sensors cannot be deployed [3]. Nodes are comprised of sensing hardware, processing capabilities, communication capabilities and low energy source. Sensor networks itself limit the nodes to perform better processing, security measures due to its power limitations. Hence nodes are unprotected or at risk to many attacks and phenomenon [4]. In WSN, a node supports multi-hop routing. The sensor based networks doesn't depend on any pre-infrastructure as in any wired networks. Each sensor participates in routing dynamically by forwarding the collected data they have sensed so far. To which node the collected data is to be forwarded is also determined dynamically. A sensor node must be operable on low power and to be operated in dense deployment environment as several nodes are densely scattered over an area to record the physical parameters and to forward them further. As we know, large number of nodes are

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required by an application, nodes must be cheaper and replaceable. From physical point of view, size of nodes should be kept small so preventing it from any kind of physical damage.
Generally, a node consists of a communicating unit (RF transceiver), processing unit (microcontroller) and power unit along with ADC/DAC and a sensor. Node is also made up of external memory[5]. The fig. 2 below shows a typical sensor node:

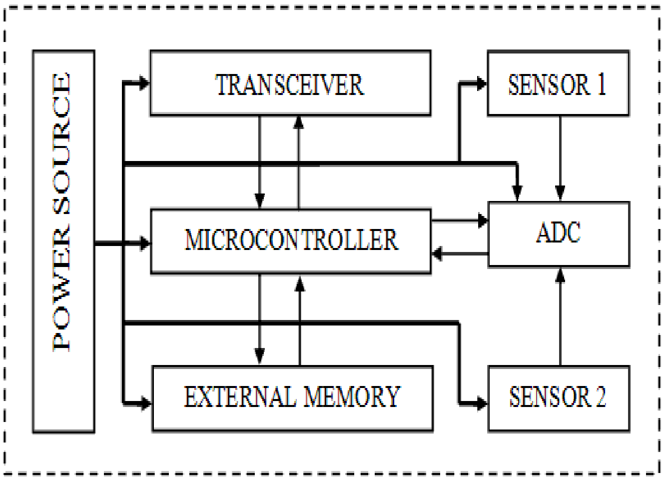

Fig.2: Sensor Node Architecture [6]

1.2 Applications of Sensor Networks

Wireless sensor networks have a lot of applications in various fields of emergency rescue operations, disaster relief, detecting chemical, environmental monitoring, habitat monitoring, home networks, biological, radiological, nuclear and explosive materials etc. Some applications for different areas are military, industrial and home networks, forest fire detection, Flood detection, Environmental control in office buildings, Health monitoring. For health monitoring, sensor will gather data to infer activities of daily living and also give clues to a person's state of health then monitor patients with dementia and other ills of aging. Early signs of disease are also possible and prevent its progression. One of the applications is monitoring bridges and building. Monitoring bridges with wireless data Sensors can be done by mounted sensors on highway bridges track conditions that affect stability. For older bridges, the data provides an objective view of the bridge's condition and safety. To monitor bridge 10 to 20 sensors can be used. Wireless sensor networks applications also in various fields like Home automation, Industrial monitoring and consumer electronics, security and military surveillance, Environmental sensing. The air conditioning and heat of most buildings are centrally controlled. Therefore, the temperature inside a room can vary by few degrees. Sensors detect the events first, and then it processes them if it is possible. After processing those data it will send it to the sink. For that, sensor nodes utilize its energy for sensing, processing and transmission purposes.

1.3 Motivation of the work

The main goal of power management is to enhance the lifetime of WSN and preventing the connectivity of the network from degradation as mostly devices have limited battery life. In WSN, if sensor network once get deployed, it will be impossible to replace each and every battery present in WSN if battery gets emptied. For this sake, we have to follow some power conservation technique to save the energy. During each and every idle period slot, we can't turn the radio off blindly, after some time to save the energy, we will not be able to expend more energy than if the radio has been left in ON state for some continuous time. So power conserving will be efficient only if energy saved is more than energy expended in state of sleep mode [7].

II. Related Work

The lifetime of a sensor node mainly depends on battery life [8]. In many cases, the WSN node has a limited power source and restocking of power may be limited or impossible completely [9]. Increasing the life time of a node in WSN - or increasing the life time of whole network, mostly depends on the power consumption of nodes in that networks. Therefore, power saving is becoming a searching topic for many researchers in the last few years. In [10] a technique known as power management is introduced. In this technique, nodes are generally in one of the two modes: the ACTIVE mode where nodes transmit and receive data and the SLEEP mode where nodes can rest down to reduce their energy. In other words we can say nodes turn off their network interface and nodes are not able to send or receive data at that time, but they save energy. In PCM, proposed in [11] before sending or receiving any packet, a handshake protocol takes place between the transmitter and the receiver. These handshake messages include RTS and CTS. Here RTS means request to send (RTS) and CTS means clear to send (CTS) signal. The main purpose of these handshake messages is to intercept collisions and telling the node what required transmission power for data and acknowledgment message packets. Directional antennas are also used to reduce energy consumption. Kranakis et al [12] compared directional antennas and omni-directional antennas. Directional antennas transmit in single direction whereas Omni-directional antennas transmit in all the directions and they ingest unnecessary energy. However, directional antennas mainly focus their radio frequency (RF) energy in a particular direction where it is needed [13] alike in omni-directional antennas. Wieselthier et al [14] proposed that using directional antennas, power can be conserved by concentrating transmission energy in a particular direction. Power Aware Routing (PAR) [15] is a protocol that increases the period time of the network and reduces the energy consumption by establishing the route between source and destination. PAR selects the minimum total transmission power path to maximize the life time of network. Chatterjee et al [16] have incorporated PAR where the issues of energy efficiency and power aware data routing strategies were addressed within an ad hoc network as crucial criteria while determining the route for a data packet to transmit. Chen, B. Jamieson et al.[17] proposed SPAN. In SPAN, a "coordinator" is selected from all nodes or sensors in the network to act as an access point (AP). Snow et al [18] shows how a low power, Time Division Multiple Access (TDMA) protocol can be implemented over a wireless network. The On-demand wake up scheme is also used to conserve the power [19].

III. Power Issue and Problem Formulation

WSN's are superior than wired sensing systems excepting that the later require a separate twisted shielding pair wire connection. Thus, implementation costs are high. To achieve cost minimization, a WSN has to function for an extensive period of time to retain cost minimization and to complete its specific goal successfully. Between life expectancy of WSN and power consumed in any network operations there is a trade-off. Firstly, when nodes are smaller in size, capacity of batteries is always limited and continuous operations of nodes uses more energy and make the nodes inoperable. Secondly, replacing batteries is not possible or impractical when there are hundreds of nodes spread over a large area. So, conserving energy is very important and is a major challenge in this wide-spreading technique.However, investigation of sources of energy consumption is must to investigate the problem properly. So these energy sources will be considered in the following:

Equation 1 defines the power consumption *Pc* in terms of supplied power *Ps* and available power *Pav*. Further, main sources of energy consumption can be classified into effective power dissipation *Pe* and ineffective power dissipation *Pi*.

$$Pc = Ps - Pav = Pe + Pi \quad ....(1)$$

Pi is the energy which is wasted because it doesn't contribute to the functionality of the network. It is mainly power consumed by control packet overhead, idle listening, over emitting and collisions. In control packet overhead, power is wasted in handling the network operations i.e. topology control and routing. In idle listening, receiver comes to active state instantly and waits for the incoming packets. In over emitting, packets are transferred to the neighbouring node but receiver node is not ready for receiving the packets. In Collision, multiple transmissions occur simultaneously.

Pe, on the other side, is the power consumed during sensing, processing requests and transmitting/receiving packets. Firstly, the sensing subsystem converts the surrounding phenomena's into electrical signal. Equation 2 indicates the power consumed in measuring mode *Pmes* and sleep mode *Pslp* of operation. *Tmes* and *Tslp* indicates the time spent in measuring mode and in sleep mode respectively.

$$Esensor = (Pmes \times Tmes) + (Pslp \times Tslp) \quad ......(2)$$

The processors in many nodes have the ability to perform also in various low power modes. For example, MSP430 processor functions in an active mode and five low power modes by disabling the CPU and some clock signals [20]. As equation 3 describes the energy dissipated by processor in active mode *Pact* and N low power modes i.e. *lpm*1, *lpm*2, *lpm*3.......*lpm*N.

$$Eprocessor = (Pact \times Tact) + \sum_{x=0}^{N}(Plpmx \times Tlpmx) \quad ....(3)$$

Equation 4 portrays the power which is used up in each state which is proportional to the operational frequency *f* and square of the supplied voltage *V* and here *C* is the total capacitance [21].

$$Pstate = C \times f \times v^2 \quad state \in \{act, lpm1,.., lpmN\} \quad ......(4)$$

Radio communication uses much more energy during task as compared to other tasks. Various studies show that the energy cost in transmitting a single bit of information is same as the energy needed in processing a thousands of operations in a sensor node [22]. Fig. 3, states a comparison between power consumed by various subsystems of sensor nodes (CM5000MSP) [23]. Equation 5 indicates the energy, required to broadcast *k* bits of information in a distance *d*. Here, *Eelec* is 50 *nJ/bit* and ∈*amp* is 100 *pJ/bit/m2*. Equation 6 calculates the energy consumed during the process of data listening through *Ton* seconds [24]. Ultimately, the total energy dispersed in radio communication Prdc can be calculated by multiplying the power consumed in each state (**tr**ansmit, **rec**eive, **idl**e, **sl**ee**p**) by the time spent in that state, as shown in equation 7.

$$ETx(k, d) = (Eelec \times k) + (\in amp \times k \times d^2) \quad ....(5)$$

$$ERx = Prec \times Ton \quad ....(6)$$

$$Eradio = \sum(Pstate \times Tstate) = (Ptr \times Ttr) + (Prec \times Trec) + (Pidl \times Tidl) + (Pslp \times Tslp) \quad ....(7)$$

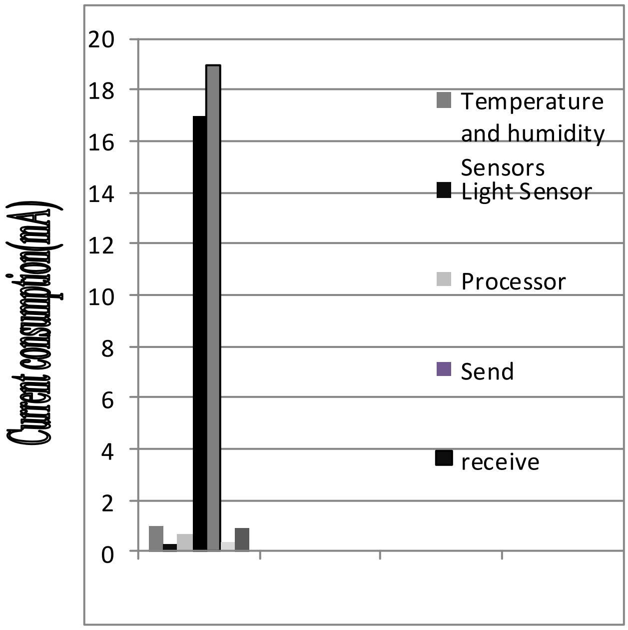

Fig. 3: Comparison of power consumed by different subsystems [25]

Fig. 3 clearly shows that receiving task consumes more energy than the transmitting task. Instead of this, it depends on the transceivers. Power consumed by a transceiver mostly depends on the methods of data aggregation(event driven, periodic sampling, store and forward) and number of bits transmitted in each transmission. In event driven, calculated readings are sampled periodically but transmission decision is taken when these readings go beyond a predefined threshold value. In periodic sampling, transmission takes place immediately after sampling. In store and forward, transmission is managed periodically time to time. In a general sense:

$$Pps > Psf > Ped$$

where *ps* stands for power consumed in periodic sampling, *sf* for store and forward and *ed* stands for event driven.

IV. Analysis

In Data-centric or Flat type of routing protocols, power usage is limited in most of the protocols but in case of hierarchical routing protocols, power usage is more i.e. in LEACH, PEGASIS and TEEN & APTEEN and is limited in TTDD. In location based routing protocols, it is limited such as in GEAR and in GAF protocols. Data aggregation is possible in almost all the data-centric routing protocols but in hierarchical protocols, it is possible in some protocols such as in LEACH, VGA and in TEEN & APTEEN and is not possible in PEGASIS and TTDD. Data aggregation is not possible in location based routing protocols. Scalability is limited in data-centric, location and in QoS based routing protocols whereas in hierarchical routing protocols, scalability is good in LEACH, PEGASIS, HPAR and VGA. Almost all the Data-centric and QoS based routing protocols are query based but hierarchical and location based routing protocols are not query based. Only QoS based routing protocols provide quality of service and remaining doesn't provide any kind of quality of service. Mobility is possible or limited in case of Data-centric and Location based routing protocols whereas it is not possible in Hierarchical or QoS based routing protocols. Following table briefly describes the comparison of various routing protocols having various parameters.

Comparison of Power in Transmission and Routing by Different protocols

Routing Protocol	Classification	Power Usage	Data Aggregation	Scalability	Query Based	QoS	Mobility
SPIN	FLAT	Limited	Yes	Limited	Yes	No	Possible
EAR	FLAT	N/A	No	Limited	Yes	No	Limited
CADR	FLAT	Limited	Yes	Limited	No	No	No
COUGAR	FLAT	Limited	Yes	Limited	Yes	No	No
DD	FLAT	Limited	Yes	Limited	Yes	No	Limited
ACQUIRE	FLAT	N/A	Yes	Limited	Yes	No	Limited
Rumor routing	FLAT	N/A	Yes	Good	Yes	No	Very limited
LEACH	Hierarchical	Maximum	Yes	Good	No	No	Fixed BS
PEGASIS	Hierarchical	Maximum	No	Good	No	No	Fixed BS
SOP	Hierarchical	N/A	No	Low	No	No	No
HPAR	Hierarchical	N/A	No	Good	No	No	No
VGA	Hierarchical	N/A	Yes	Good	No	No	No
TTDD	Hierarchical	Limited	No	Low	Possible	No	Yes
TEEN & APTEEN	Hierarchical	Maximum	Yes	Good	No	No	Fixed BS
GEAR	Location	Limited	No	Limited	No	No	Limited
SPAN	Location	N/A	No	Limited	No	No	Limited
GAF	Location	Limited	No	Good	No	No	Limited
MFR,GEDIR	Location	N/A	No	Limited	No	No	No
SAR	QoS	N/A	Yes	Limited	Yes	Yes	No
SPEED	QoS	N/A	No	Limited	Yes	Yes	No

V. Conclusion

Sensor nodes will also consume little amount of energy in its idle and sleep mode. Most of the energy in WSN is consumed during the send and receive operation of data. Therefore, data is to be processed in network. Data is to be transmitted only if it is absolutely necessary. The choice of transmission protocol also makes effect in conservation of energy. Therefore, proper transmission protocol should be chosen for particular type of network.

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