Traffic based energy consumption analysis and improve the lifetime and performance of MAC protocols in ad hoc wireless sensor networks

Dharam Vir*, Dr. S.K. Agarwal, Dr. S.A.Imam*****

*(Department of Electronics Engineering, YMCA University of Science & Technology, Faridabad, India - 121006)

** (Department of Electronics Engineering, YMCA University of Science & Technology, Faridabad, India - 121006)

*** (Department of Electronics & Comm. Engineering, Jamia Millia Islamia, New Delhi, India - 110019)

ABSTRACT

Wireless microsensor networks lend themselves to trade-offs in energy and quality. The service lifetime of such sensor nodes depends on the power supply and energy consumption of nodes, which is usually dominated by the communication subsystem. One of the key challenges in unlocking the potential of such data gathering sensor networks is conserving energy so as to maximize their post deployment active lifetime. This paper described the research carried on the continual development of the novel energy efficient analysis of random placed nodes algorithm that increases the WSNs lifetime and improves on the QoS parameters yielding higher throughput, average end to end delay jitter for next generation of WSNs. Another key advantage of the novel analysis of random placed nodes algorithm is that it can be implemented with existing energy saving protocols like LEACH, SMAC and TMAC to further enhance the network lifetimes and improve on QoS parameters. The main aim of this paper is to improve energy in nodes and to analyze the most energy efficient MAC protocol in order to classify them and compare their performances. We are implemented some of WSN MAC protocol under QualNet 5.0 with the purpose to evaluate their performances.

Keywords - MAC protocol, Energy consumption, Delivery ratio, Throughput, Delay

I. INTRODUCTION

Ad hoc wireless sensor networks (WSNs) are formed from self-organising configurations of distributed, energy-constrained, autonomous sensor nodes. The nodes are microelectronics devices is equipped with heavily integrated sensing, processing, and wireless communication capabilities and are equipped with an independent power source, such as a small battery [1]. When these nodes are networked together in an ad-hoc fashion, they form a sensor network. The nodes gather data via their sensors, process it locally or coordinate amongst neighbours, and forward the information to the user or, in general, a data sink. Another cause for energy consumption in the MAC layer is idle channel sensing. If the nodes receive scheduling packets or want to transmit a message they need to sense the channel very often and wait until the channel is sensed idle, and that consumes energy. In a shared medium, the data transmitted by one node is received by all nodes within that transmission range; hence a node may waste energy in receiving packets that are not destined for it. Nearly all the MAC protocols operate by sending control packets of different types e.g. synchronization, scheduling, RTS, CTS, ACK etc, this results in more energy consumption for resource limited wireless sensor nodes. From above it can be concluded that not only is the energy consumption and network lifetime an important issue, but network throughput can also be not ignored. However a balance needs to be made between network lifetime and throughput based on requirements of the application. The service life of such nodes depends on the power supply and the energy consumption, which is typically dominated by the communication subsystem. One of the key challenges in unlocking the potential of such data gathering sensor networks is conserving energy so as to maximize their post-deployment active lifetime [2]. Research has been carried out in many different areas of WSNs from enhancing medium access control (MAC) protocols to improving topology management schemes where energy can be reduced. Many of the efficient MAC routing protocols try to increase the network lifetime by transitioning the idle nodes to sleep state. This not only increases the overhead cost of introducing synchronisation packets, but also has detrimental effects on the network QoS parameters that introduce end to end delay, average jitter and results in decreased throughput [1] [5].

The purpose of putting nodes to sleep is more useful for nodes that are furthest away from the base station. In the case of the nodes nearest to the base station, having much higher traffic to forward at peak rates these nodes cannot actually share the same sleep-awake schedule that is planned for the rest of the WSN. In energy efficient routing protocols, lot of emphasis is given on minimising the transmission energy consumption, by either introducing multi-hop in the network, or finding the minimum energy route, where the message will be sent via a calculated multi-hop route. These protocols fail to scale the size of the networks. The majority of these protocols which is finds the minimum path and then always chooses that path regardless of the amount of traffic. Hence nodes required to forward messages in that minimum energy path list will always die first. These protocols fail to address the issue of energy consumption based on traffic. In many wireless sensor networks, the nodes nearest the base station will always be the busiest as traffic will be approaching these nodes from all directions of the sensor fields. These nodes provide the last hop for a successful transmission. One of the significant differences between the new power analysis random algorithm introduced in this paper and the existing energy saving protocols is that the new power analysis of random algorithm for balances the energy on the network traffic and also introduces ideal mode that further extends network lifetime by saving idle energy consumption. This balances the energy consumption of sensor nodes at all stages of the network. At a point furthest away from the base station, the transmission distance is longer as the traffic is much lower and the nodes can afford to transmit at a longer distance. For nodes nearest to the base station, where the traffic is higher, the transmission range is intelligently calculated to be shorter, so more data can be forwarded to the base station without consuming all the cluster head energy [3] [6].

To evaluate the QoS parameters in terms of throughput, average end to end delay and average jitter for analysis of randomly placed nodes in the network.

The rest of the paper is described in section 2 MAC protocol leads to energy waste and lifetime parameters. Section 3 describes the classification of wireless MAC protocols. Section 4 Energy efficient routing protocol analytical and simulated models for 802.11e and 802.11. Section 5 QualNet simulation and results analysis. Section 6 conclusions generated by the current work and discuss possible future work.

II. MAC PROTOCOL LEADS TO ENERGY WASTE AND WSN LIFE REDUCTION

The MAC protocol leads to energy waste and WSN life reduction, such as:

1) Idle listening:

A node doesn't know when will be receiving a frame so it must maintain permanently its radio in the ready to receive mode, as in the DCF method of the wireless networks protocol (IEEE 802.11). This mode consumes a lot of energy, nearly equal to the one consumed in receipt mode. This energy is wasted if there isn't any transmission on the channel [7].

2) Collisions:

They concern the MAC contention protocols. A collision can occur when a node receives two signals or more simultaneously from different sources that transmit at the same time. When a collision occurs, the energy provided for frame transmission and reception is lost. [4] [7].

3) Overhearing:

It occurs when a node receives packets that are not destined to him or redundant broadcast.

4) Protocol Overhead:

It can have several origins as the energies lost at the time of transmission and reception of the control frames. For example, the RTS/CTS (Request to send /Clear to send) used by some protocols transport no information whereas their transmission consumes energy [8].

5) Overmitting:

It occurs when a sensor node sends data to a recipient who is not ready to receive them. Indeed, the sent messages are considered useless and consume an additional energy [8].

6) **Packets size***:*

The size of the messages has an effect on the energy consumption of the emitting and receiving nodes. In the other case, a high transmission power is necessary for large size packets [9].

7) Traffic fluctuation:

The fluctuations of the traffic load can lead to the waste a node's energy reserves. Therefore, the protocol should be traffic adaptive. In, the authors introduce a comprehensive node energy model, which includes energy components for radio switching, transmission, reception, listening, and sleeping [9].

III. Classification of Wireless MAC Protocols:

In a wireless sensor network sensors nodes are a low cost, resource constrained devices and are often positioned randomly. In many applications they are placed in inaccessible locations, making battery replacement unfeasible. As a consequence, power efficiency is an important requirement in a medium access control protocol for most wireless sensor networks. The simplest way to conserve energy by the MAC layer protocols is by turning off the radio whenever the node is not transmitting hence leaving the node in sleep mode. Radio energy consumption is a major component contributing to the overall energy consumption at each node. The wireless MAC protocols can be divided generally in three main categories, Centralised, Distributed & Hybrid MAC Protocols as shown in Figure 1 [9] [14].

1) Centralised MAC Protocols:

In centralised MAC protocols, it is the responsibility of a single controller to allocate the channel access for all the nodes in the sensor field to provide a collision free environment. Channel multiplexing techniques similar to Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) have been mentioned. Due to limited channel bandwidth and very large number of nodes, when implementing FDMA, it becomes impractical for each node to have a unique operating frequency [8] [10].

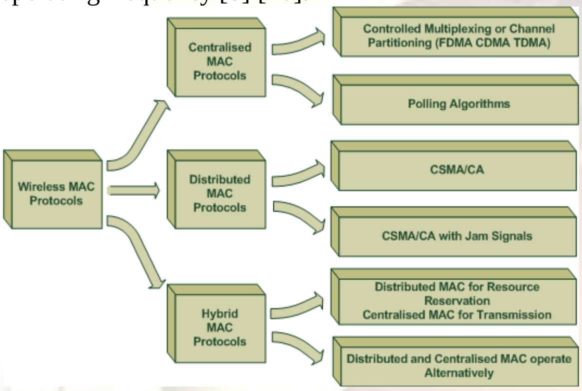

Figure 1. Classification of Wireless MAC Protocols.

2) Distributed MAC Protocols:

These MAC protocols allow multiple channel access to all the participating nodes based on some rules. The prime example of this protocol is CSMA/CA, where all the participants regularly sense the medium to see if it is idle. If the channel is found to be busy, the transmission is deferred until the channel becomes idle. The probability of collisions are avoided by introducing a time delay procedure e.g. random back-off procedure as employed in IEEE 802.11 distributed coordination function (DCF). However the packet collision cannot be completely avoided in distributed MAC protocols due to the “hidden” and “exposed” node problem which has a very large impact on the network QoS. To overcome this problem the DCF uses RTS and CTS control messages to reserve the transmission time between two nodes [8] [13].

3) Hybrid MAC Protocols:

The existing centralised and distributed MAC protocols do not provide analyses of energy saving and network scalability for WSNs. An ideal protocol would exhibit the controllability of centralised protocols and the flexibility of distributed protocols. WSNs have unique characteristics e.g. low energy reserves, compact hardware, small transmission ranges, event or task driven and have high redundancy [7] [11].

IV. ENERGY EFFICIENT ROUTING PROTOCOLS:

This paper is primarily based on finding new and effective routing algorithms to minimise the energy consumption of wireless sensor networks. Ad hoc wireless networks do not have any network infrastructure. The wireless nodes in the ad hoc network try to maintain connectivity via wireless communication. The power aware wireless routing protocol is two basic classifications; Activity based routing protocols and

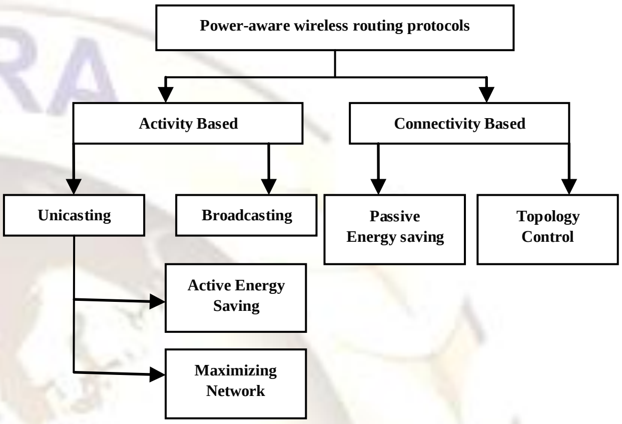

Figure 2. The classification of energy efficient wireless ad hoc routing.

Connectivity based protocols [10] [12]. Fig. 2 shows the classification of energy efficient ad hoc routing protocols. The energy efficient routing protocols can broadly be divided into five categories, active energy saving protocols, maximizing network lifetime protocols, passive energy saving protocols, topology control protocols and broadcasting protocols.

A. Maximizing Network Lifetime Protocols:

The protocols associated with maximizing the network lifetime and balance the energy consumption of all the nodes in the network to overcome the problem of overuse of some nodes. One way to minimize energy consumption is to use the Minimal Battery Cost Routing (MBCR) [13]. In this routing protocol the total energy consumption of different routes is calculated adding the battery cost for each hop until the packets reaches destination. The aim is again to find the lowest energy consumption path [11].

1) Components of a Wireless Ad hoc Sensor network:

In order to fully understand the characteristics and behavior of wireless sensor networks, we need to define all the components that can be considered vital in the abstract simulation model. The following is the list of the important components that will constitute our simulation model.

- There will be fixed or immobile devices, called nodes that have data processing and data transmission capabilities. These nodes will be powered by on-board batteries that have limited energy. The nodes also need be equipped with geographic localization devices [14].
- As nodes will have communication capabilities, e.g. either with the base station or with other nodes within their vicinity, they will closely follow the rules and algorithms defined by the OSI protocol stack. Hence all the nodes will have their communications regulated by the characteristics associated to the OSI protocol layers: application, presentation, session, transport, network, data link, (MAC), and physical layer [14].
- Node energy power relies on the use of on board batteries. Every action involving the use of the radio has energy cost. As the nodes will be communicating with the base station or with their neighbours, they will be consuming energy in the transmission or reception of packets. When device is switched on or off, consumes energy, hence affecting the available energy and node life.
- The transmission model also need to be dynamic as the transmission range will need to be varied depending on the amount of traffic at different parts of the network.
- Radio propagation is affected by the adverse environmental conditions in which the network is placed.
- The traffic load varies at different locations in the network. Different traffic loads can be created using Constant Bit Rate sources (CBRs). CBR sources needs to be incorporated with the abstract simulation model [14].

A. Selection of Network simulators for WSNs:

QualNet (Quality Networks) work from Scalable Network Technologies is a commercial product that is an improved modeling tool derived from GloMoSim. It has a dedicated and fully implemented protocols and modules for both the wired and wireless scenarios including ad hoc, cellular and satellite models. The Simulator, this component is designed to include high fidelity models of networks of tens of thousands of nodes with heavy traffic and high mobility.

B. Analytical and Experimental Model for 802.11e and 802.11 using QualNet 5.0 Simulator:

The default values for all parameters in the configuration file of QualNet were used, i.e., the transmission rate is set at 11 Mbps, and the power consumption is 900 mW for both receiving/idle and transmitting states. The transmission range for each node is 100m (receiver threshold is -75dB). CBR traffic is generated from node 1 to 30 times with 5 second interval; the data size is 512 bytes and simulation time is 300 seconds [15].

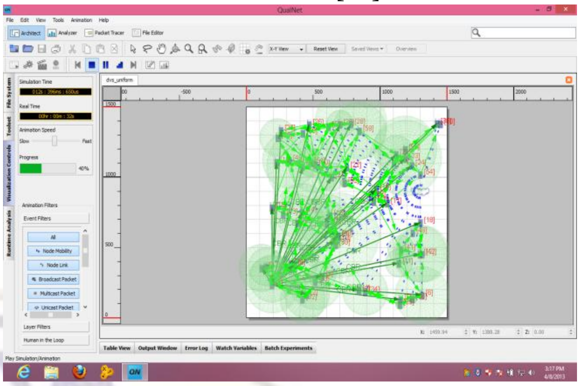

Figure 3. Routing path of data (source to sink) running scenarios of 30 nodes for maximizing the lifetime of node in random algorithm

V. Result Analysis

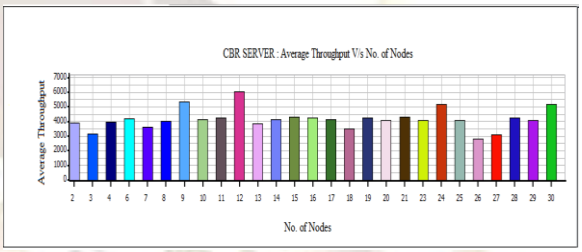

Figure 4. Shows the outcome of average throughput for randomly placed nodes.

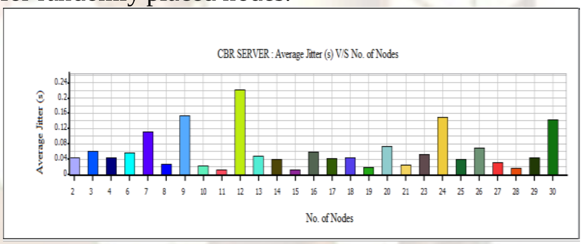

Figure 5. shows the outcome of average jitter in randomly placed nodes.

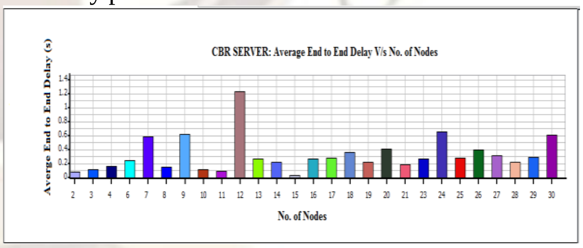

Figure 6. Shows the outcome of average end to end delay (s) in randomly placed nodes.

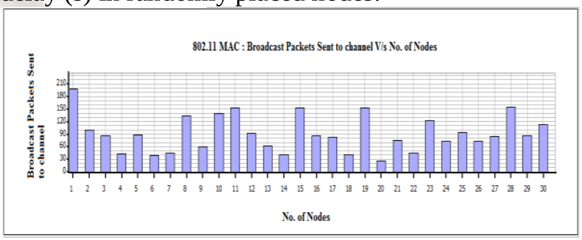

Figure 7. Shows the outcome of 802.11MAC Broadcast Packets Sent to channel in randomly placed nodes.

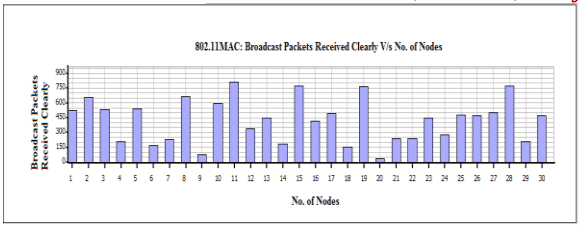

Figure 8. Shows the outcome of 802.11MAC Broadcast Packets received clearly in randomly placed nodes.

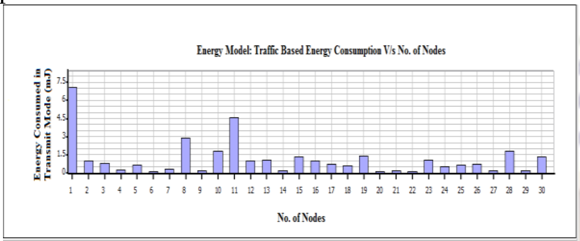

Figure 9. Shows the outcome of energy model traffic based energy consumption in transmit mode randomly placed nodes.

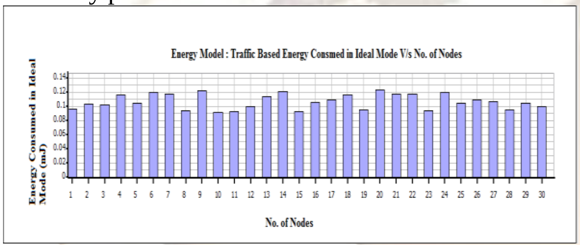

Figure 10. Shows the outcome of energy model traffic based energy consumption in Ideal mode randomly placed nodes.

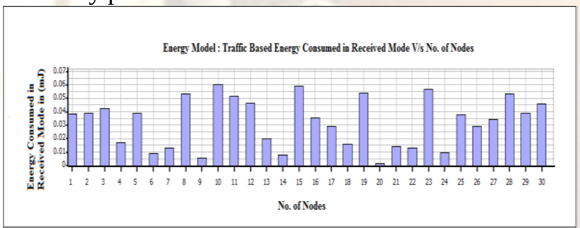

Figure 11. Shows the outcome of energy model traffic based energy consumption in received mode randomly placed nodes.

VI. CONCLUSION

Ad hoc wireless sensor networks (WSNs) are formed from self-organising configurations of distributed, energy constrained, autonomous sensor nodes. The service lifetime of wireless sensor nodes depends on the energy consumption of the communication subsystem and channel capacity being used for data transmission. This improves methodology of the 802.11 MAC protocols led to increase the lifetime of nodes and throughput of networks. On the increase in node density, average end to end delay decrease for all implemented schemes. This is due to the large no of nodes getting involves in routing, which results in quicker data delivery to the sink through these nodes.

An increase in Transmission rate provides a decrease in Energy consumption for all schemes, since all the schemes use their power conservation methods effectively in the transmitting the large number of data packets transmitted per unit of time. Moreover the startup energy overhead also decreases on an increase in the Transmission Rate. Hybrid showed the lowest Energy consumption and distributed MAC protocol scheme highest energy consumption. So increase in Transmission Rate can be opted as a good method to decrease the energy consumption in wireless sensor networks. On an increase in Transmission rate, throughput increase for all schemes because of large amount of data which is transmitted gets serviced by the communication system. Centralised MAC protocol scheme provides the very large throughput compared to other two schemes. Thus increase in transmission rate can be effective method to increase the throughput in a wireless sensor networks. An increase in transmission rate initially provide a slight increase in average end to end delay for hybrid and distributed MAC protocol schemes. The distributed MAC protocol provides the minimum delay. Therefore the increase in Transmission rate has very little effects on the average end to end delay encountered by the data packets in a wireless sensor networks. The bandwidth decreases in a wireless sensor network having a higher error rate. In a wireless sensor network, on an increase in the error rate, the average end to end delay increase considerably for all three schemes. If proper adoptive schemes are used in a wireless network, the average end to end delay encountered by the data packets can be considerably reduced, which is proved in the superior performance exhibited by all schemes.

Future work:

This work had implemented an energy efficient channel adaptive MAC protocol in a wireless sensor network with static nodes. This scheme had provided improvement gain in Energy efficiency, throughput, bandwidth, average end to end delay and delivery ratio. But the superior nature of this scheme depends on many environmental factors. Such as operation scenarios, specific data type etc.

REFERENCES

[1] T. van Dam and K. Langendoen, "An adaptive energy efficient MAC protocol for wireless sensor networks," in *ACM SenSys 03, November 2003.*

[2] Heinzelman, W. R., A. Chandrakasan, et al. (2000). "Energy-efficient communication protocol for wireless micro-sensor networks." System Sciences, 2000. *Proceedings of the 33rd Annual Hawaii International Conference*.

[3] V. Rajendran, K. Obraczka, and J. Garcia-Luna-Aceves, "Energy-efficient, collision-

free medium access control for wireless sensor networks," *in ACMSenSys 03, November 2003.*

[4] Iqbal, Q. R., D. J. Holding, et al. (2007). "Energy efficient radio range allocation in ad hoc wireless sensor networks." *Proceedings of the 2007 spring simulation multi-conference-Volume 1*: 58-65.

[5] Al-Obaisat Y, Braun R "On Wireless Sensor Networks: Architectures, Protocols, Applications, and Management*" Auswireless Conference 2006.*

[6] M. Takai, J. Martin, and R. Bagrodia. "Effects of wireless physical layer modeling in mobile ad hoc networks". *In 2nd ACM International Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc 2001), pp. 87–94. ACM Press, October 2001.*

[7] I. Rhee et al., "Z-MAC: a Hybrid MAC for Wireless Sensor Networks". *ACM SenSys, San Diego, CA, Nov. 2005.*

[8] M. Zorzi and R. R. Rao, "Energy constrained error control for wireless channels," *IEEE Personal Communications, pp. 27-33,* December 1997.

[9] W. Ye, J. Heidemann, and D. Estrin. "An Energy-Effcient MAC Protocol for Wireless Sensor Networks*". INFOCOM 2002, volume 3, pp 1567-1576, June 2002*

[10] Li, J., D. Cordes,"Power-aware routing protocols in ad hoc wireless networks." *Wireless Communications, IEEE: 69-81. (2005).*

[11] V. Rajendran, K. Obraczka, and J. Garcia-Luna-Aceves, "Energy-efficient, collision-free medium access control for wireless sensor networks," *in ACMSenSys 03, November 2003.*

[12] Giridhar, A. and P. R. Kumar (2005). Maximizing the functional lifetime of sensor networks, *IEEE Press Piscataway, NJ, USA.*

[13] S. Singh and C. Raghavendra. PAMAS: Power aware multi-access protocol with signalling for ad hoc networks. *ACM SIGCOMM Computer Communication Review, vol. 28(3):pp*. 5–26, July 1998.

[14] Y. Tseng, C. Hsu, and T. Hsieh. "Power-saving protocols for IEEE 802.11-based multi-hop ad hoc networks". *In 21st Conference of the IEEE Computer and Communications Societies (INFOCOM 2002), vol. 1, pp. 200–209. New York, NY, June 2002.*

[15] QualNet 5.0 user manual. http://www.scalablenetworks.com