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Analysis of Energy Consumption and Data Delivery Delay in Wireless Sensor Networks

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Abstract: ***Environmental disasters such as landslide, earth quake and water flooding may occur at time without any prior notification. It is very much needed to protect the residential areas from these sudden disasters, due to change in environment conditions. In such situation ,losses may be minimized by using systems which can work fast in communicating the information without any delay. This paper addresses a technique using Wireless Sensor Networks (WSNs) which can act fast in communicating the information with minimum delay. Wireless Sensor nodes are most helpful module to protect ourselves from environmental disasters. Sensor nodes are deployed nearer to the physical location where the disaster event occurs. Monitoring take place from the base station, which is placed at a remote place. It is needed that the data packets are received by pre determined time with minimum time delay and increasing life time of sensor nodes. Most of the time, energy is consumed by the sensor module device, when the sensor node is on all the time even when no event occurs, keeping unnecessarily the sensor node waits till receiving the data packets from the event. Considering minimization of energy consumption ,which is being done by turning-on the sensor node in sleep mode through MAC (Medium Access Control) operation. When no event occurs for a long time at disaster happening areas, immediately the sensor node goes to constant sleep mode, which leads to delaying of data packets, even though the WSNs adapting IEEE 802.15.4 standard of MAC protocol. To counter these draw backs of energy consumption and delay, instead of using MAC protocol the opportunistic routing technique, especially any cast protocols is used along with a high node density in this paper. This paper also discusses on the analytical model of the wireless sensor networks deployed in the disaster location and the analysis of trade–off between energy and its delay are done, by considering the optimum value of time period in both active and sleep mode of operation of the wireless sensor nodes.***

***Index Terms**: WSNs – Wireless Sensor Networks, active and sleep mode, disaster, MAC- Medium Access Control.*

I. INTRODUCTION

The unique capability of Wireless Sensor nodes is that it detect the events through sensing device, which is build in the individual node. Event of interest is detected by the sensor nodes when it occurs and generating the data packets for forwarding it to the next nearest neighbor node. Finally the data packets reach the base station i.e., sink node which is available at a remote place. The number of sensor nodes deployed in disaster location may be 'n' in number. The wireless sensor network may continuously monitors the physical changes in the area of its deployment that may be landslide, earth quake and water flooding. The most emergency need is to protect the living and non-living things in the surroundings. The base station receives the data packets with in the pre defined interval of time. According to the received data packets at the base station, it delivers the caution messages immediately by the way of alarm and or taking appropriate action. In 2015, Chennai city was affected by water flooding at mid night, it was a very dangerous event occurred, many people were affected by this incident. It was the natural disaster caused by gradually or a sudden rising of water level in the Chembarampakkam Lake due to heavy rain which is situated near to Chennai city. Since this Lake is not equipped with such sophisticated WSN for sensing any calamity, it will be an useful system to alert the people living in Chennai for their safety. Simultaneously the minimum energy requirements are necessary for sensor nodes, this factor is most important in order to extend the life of battery. Mainly this paper focusses on the trade-off between data delivery and increasing the life time of Wireless Sensor Nodes. This is very much important to discuss on the analysis of trade-off between energy consumption and data delivery. The IEEE standard of 802.15.4 is adapting the MAC protocol in wireless sensor networks. Active and sleep scheduling becomes an effective technique to extend the life time of sensor device. By keeping sensor nodes in sleep mode when there is no event occurred, the sensor nodes become ideal and at the same time the consumption of energy by sensor device can be reduced significantly. Wireless Sensor Networks, whose sensor nodes entering the sleep mode, leads to low–power consumption due to reductioin in its operation. Some researchers [1] developed a Markov chain model for the wireless sensor network, This Markov chain is used to evaluate the performance of the network in terms of its energy consumption and delay in data delivery. Various kinds of active and sleep scheduling protocols were proposed in [2]-[6]. Sensor nodes periodically exchanges synchronization information with their neighboring nodes. On demand active-sleep scheduling protocols was proposed in [7]-[8], where the nodes turn-off most of their modules and the secondary low-powered receiver is always turned on to listen the up coming "wake-up" command from its neighboring sensor node, in order to relay the emergency data packets.

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This paper, focusses on the trade-off between delay in data delivery and consumption of energy by wireless sensor nodes. The main analysis is done on active/sleep mode of individual

sensor nodes in the wireless sensor networks with out focusing entire network at the same time. Compromising between active and sleep time slots using opportunistic protocols between source node and destination nodes, i.e., neighbor nodes.Finding the optimum time between active and sleep mode of operation related with an analytical model. The network simulator is used to simulate the network (two node model) and verify the results with analytical model, derived the relevant equations using Markov chain model. For addressing these challenges, investigations on active and sleep mode of operation is done. Further this paper is narrated as given below. Section 2 discussed with prior work. Opportunistic routing protocols has been describes in the section 3. Section 4 presents the network timing diagram operation. The analytical model is discussed in section 5, which is used to investigate the optimum solution of active and sleep mode of operation. In section 6, the performance of results through proposed method of operation and finally made the conclusion of this paper.

II. PRIOR WORK

The entire review of wireless sensor nodes / networks has been relatively reported.Also carried out studies on network traffic condition and various protocol techniques related to active and sleep mode of operation. The PAMAS scheme which allows a node to turn-off its transceiver module at wireless sensor nodes and the use of sleep modes at the MAC layer are presented in [9]. The wake-up scheme scheduling at the MAC layer which turn-on the sleeping nodes when they are in need to forward the data packets were presented in [10]-[13] thus avoiding a degradation in network connectivity ensuring quality of service.To transmit data from sensor nodes to sink node in multi-hop WSNs based on Lagrange relaxation method was instigated in [14]to improve the energy efficiency of sensor nodes and satisfying end-to-end delay. An energy harvesting method based on the watermill principle for sensor power was investigated in [15]. The researchers of [16] addressed the minimum energy consumption concept with an increasing of time delay from end-to-end in Wireless Sensor Networks (WSNs). To meet the tradeoff between energy consumption and time delay, this paper proposes the Media Access Control (MAC) protocol using dynamic duty cycle. The duty cycle was adjusted dynamically through computing node utilization rate, average sleeping delay and considering the upper and lower bound of duty cycle, to adapt the network real-time communication flow. The opportunistic routing protocols of wireless sensor network which selects the closet node from the network for relaying the data packet was investigated in [17]. Wireless Sensor Networks haveing minimum energy, good efficiency, increased throughput and quality of service at desired level of communication is considered.

III. OPPORTUNISTIC ROUTING

In general, IEEE 802.15.4 standard wireless sensor networks are adapting MAC protocol, basically it should have only minimum energy consumption. When the sensor nodes detect the events, nodes generating the data packets and forwards from source node to closer neighbor node at the same time both the sensor nodes are in active mode (wake–up state) of operation. Suppose if we need the minimum energy consumption, sensor nodes has to go to the sleep mode of operation immediately. Since sensor nodes constantly goes to sleep mode, the data packets unlike to reach the destination node, i.e., closer neighbor node. So, the MAC protocol is not supporting the timely delivering of data packets, and leads to data delivery delay. The name of the opportunistic protocol is known as any cast protocol which fulfills both the criteria of energy consumption and data delivery delay. Based on opportunistic protocol forwarding the data packets in particular time slot have been split in to two phases. The first phase of time slot is named as watch dog time and the second phase named as forwarding cycle and sleep. Before starts to transmit the data packets, it sends the sample messages, called as beacon messages. After sending beacon messages, the sensor nodes comes to active mode from sleep mode and reports back the ACK message. The second phase of time slot will be ready to forwarding the original data packets, after receiving these data packets the sensor node goes to sleep mode. For this kind of operation the wireless sensor networks will be tolerating of both energy consumption and data delivery delay. The beacon message, ACK message and data packets, all these data operates under duty cycle operation. MAC protocol also operates under duty cycle. When using low duty cycle operation, the minimum energy consumption occurred at the MAC protocol. But for the same rate of duty cycle (low – duty cycle) of operation , opportunistic protocol, gets a trade-off between delay in data delivery and energy consumption . The beacon message duty cycle is very smaller than data packet duty cycle. We assumed that both the duty cycles are not synchronized.

IV. NETWORK TIMING DIAGRAM OF NODE OPERATION

The node operation timing of any-cast protocol is given in Figure 1. Each and every sensor node except the sink node operates under duty cycle, and also the length of the cycle is considered as T_p. The duty cycle is divided into two slots. These two slots duration are denoted as T_{wd} and T_{f_sleep}, respectively. It is advisable to have a very low duty cycle, in order to achieve long network lifetime and so $T_{wd} \ll T_p$. The transmission process of the packet is done as follows.The node initially broadcasts short beacon messages periodically, when it has a packet to send. [If any node which is monitoring on the channel will receive the beacon message and it checks the following norms, (1) Whether the received beacon message possess a higher signal to noise ratio (SNR) than a given threshold or not (2) and the node is closer to the sink node than the sender node or not. The first norm is to ensure that due to channel quality the packet is having low error rate. If both these norms are satisfied, the receiver responds with a CTS message. Multiple nodes may receive the beacon message. Simlarly, the sender may receive multiple CTS messages from its neighbor nodes. The first node that replies with a CTS message is chosen as the next hop node. Then the sender transmits the data packet to it finally.

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The beacon messages are set with a transmission interval equal to T_{wd}, and is shown in Fig.1, to ensure that the beacon messages can be received by other nodes also when they are watching. Therefore, during the watch dog phase, each node receives a beacon message from its neighbors, when there is a transmission of beacon messages. Moreover, it is assumed that there is no collision between the messages from different nodes. In monitoring applications the duty cycle is normally very small. Also the CTS messages and the beacon message are very short and are unlikely to collide each other. Their length may be very small compared to the listening period, even though the data packets are longer. In the rare case of data packet collision, to ensure delivery, retransmissions after a short amount of delay may be done by their senders. Considering an example of a typical monitoring WSN application,,in which the watching phase duration T_{wd} may be set to 100ms and the operation cycle T_p may be set to 10s, to achieve a 1% duty cycle.

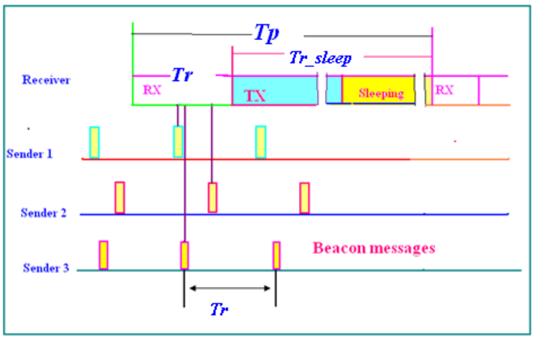

Fig.1 The timing diagram of node operation

As shown in Fig 1.,for many WSN platforms the transmission duration of a CTS message or a beacon message is less than 1ms and for a data packet with 50 bytes the transmission duration is less than 2ms. Thus the probability of collision in this case is minimal and can be neglected.

V. ANALYTICAL MODEL

Let $P(S_o, S_d)$ be the probability of transition time period, where in one time slot the chain moves from source node state S_o to neighbor node state(destination node) S_d. Each sensor node have sleep/active mode of operation. The input parameters p and q determines the mode of operation. The data packets generation process is denoted by g, where g is the probability that a data unit is generated in a particular time slot by the individual sensor node. The receiving data packet unit from neighboring node is denoted with α . That data packet unit forwarded is denoted as , which gives the probability of a data unit which is forwarded in a time slot. The DTMC (Discrete Time Markov Chain) model describes the active /sleep mode of operation of the sensor's next hops. Let us consider the stationary distribution of the entire DTMC by $\pi = \{\pi_s\}$, in which the generic state of the model ia denoted by '*s*'. The sensor model is solved to get the value of π and the following metrics are derived. Generating data packets in a particular time period for single sensor node is given below in equation (1)

$$\lambda = \sum_{i=0}^{\infty} (R_i^F + R_i^W) \; g \qquad (1)$$

Consider the individual sensor node to study about the behavior of the node through the DTMC model. In the DTMC model the time allotted is based on time slot of data packets forwarding time. Moreover, the DTMCs will be solving the individual sensor node behavior. The sensor network model involves the changes resulting from the synergy between the sensor and the closer neighbor nodes to it. The clear DTMC is defined by the cycle phase in which the sensor nodes present time slot and it is denoted as *S, A* and *N* the infinity number of data packets accumulated in the buffer. Also each individual nodes are having separate sensor buffer stage and it is helpful to store the queued state of data packets.The different phases are indexed with the number of data packets stored in the sensor buffer. Assumed that all the sensor nodes boundary line of radius *'r'* in a circular disc area in order to avoid complication due to edge effects. Considered two nodes '*i*' and '*j*' if $\gamma_{i,j} \leq \gamma(n)$ then forwards the data packets. Let $\gamma_{i,j}$ be the distance between nodes *i* and *j* node where *i* and *j* are said to be neighbors. Moreover, node *i* can successfully forwards data packets to node *j* only if *i* is a neighbor of *j* and no other neighbor of *j* is forwarding concurrently with *i*. The average number of outgoing (forwarding) data packets by the sensor node in a particular time period is denoted as Ʈ,

$$Ʈ = \sum_{i=1}^{\infty} (R_i^F + N_i^W) \; \beta \qquad (2)$$

The data packets stored in the buffer. Each node has buffer that can BE occupied with the data packets when there are more number of packets queued in a time period as mentioned in the Equation 3.

$$B = \sum_{k=1}^{\infty} k[(R_k^F + R_k^W + N_k^F + N_k^W)] \qquad (3)$$

The unknown metrics of *α, β, w* and *f* are evaluated by simulation for the sensor network model to derive the stationary distribution of DTMC. The Equations (1-4) are used to compute and verify the values.

We assumed that data packets are not dropping against collision, traffic congestion and /or long time waiting to delivery, that means queuing or more data packets stored in the buffer state. Consider the network capacity '*C'* by means of localized or unlocalized traffic condition of wireless sensor networks.

$$C = \sum_{i=1}^{v} \lambda^i \qquad (4)$$

The total packets which the sensor nodes forwarded is denoted by F'. It includes both the data packets generated by individual nodes and data packets received by the neighbor nodes that can be given in the Equation 5.

$$F' = ƮB + \lambda \qquad (5)$$

The individual sensor node has 4B states, which is described by Markov chain , and '*B'* is the sensor buffer size. The average data delivery delay '*D'* is the average time needed to forward a data packets from one of the sensor which can detect the event of interest to the closes neighbor sensor node, derived from the Little's formula as given in the Equation 6.

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$$D = \frac{\sum_{i=1}^{n} F'}{C} \qquad (6)$$

The average energy consumption per time slot is denoted as '*E*'. This can be spilt in to three contributions. We show that the first energy consumption of networks as taking individual nodes, considering the energy consumption of the node which also depends on the mode of operation is given as below.

$$E = \sum_{i=1}^{n} \left[\pi_S^i E_s + \left(\pi_N^i + \pi_R^i\right) E^{(ideal)}\right] \qquad (7)$$

Where, E_s is the energy consumption in sleep mode, $E^{(ideal)}$ is the energy consumption in ideal mode.

The other two additions are 1) energy required expected to forwarding and receiving data packets and 2) the energy spent during the changeover from active mode to sleep mode. Then the energy consumption due to the above said contributions are given as follows,

$$\bar{E} = \sum_{i=1}^{n} \left[T^i \sum_{j \in H^i} \left(E_{i,j} R(i,j)\right) + \pi_{s0q}^i E^t \right] \qquad (8)$$

Where, $E_{i,j}$ is transition energy consumption from node *i* to *j* and the transition probability *R(i, j)* can be computed as follows,

$$R(i,j) = k \left(\prod_{m \in N_{i,j}} \left(\pi_s^m + \pi_N^m\right) \right) \pi_R^j \qquad (9)$$

Where, $N_{i,j}$ denotes the set of later-hops that are having greater priority than *j* in routing table of *i* and *k* denotes the normalization factor. The DTMCs having single node behavior are individually computed to each other. The dynamics are the results of the interactions between the source node and sink node. Each individual nodes are having separate sensor buffer stage and it is helpful to store the queued state of data packets during the cycle phase of DTMC

VI. RESULTS AND DISCUSSIONS

Many results are derived under various load conditions. The parameters for conditions of traffic load and the theoretical traffic load is expressed as follows,

$$G = \frac{gv}{p + q} \qquad (10)$$

where, g is the sensor data packets generation rate and *p*, *q* are the transition rates of sleep/active. Table 1 shows the parameters considered for this work. Note that *G* denotes the sum of generation rates of all nodes. Fig. 2 shows the energy consumption with respect to the active period of sensor nodes.

Table 1. Simulation Parameters

Parameters	Specification values
Sensor nodes, *n*	100
Operation cycle, T_p	10sec
Phase duration, T_{wd}	100ms
Transmission duration	>2ms
Data packet size	50 bytes
MAC	IEEE 802.15.4
Route value, *M*	2-5
Generation rate of nodes, *G*	0.4-0.9
Initial energy	0.12mj

Average number of active node sensors are considered in the network and fixed the number of route value, *M=2* for both analytical and simulation and also the network load should be fixed at the value of *G=0.4*.

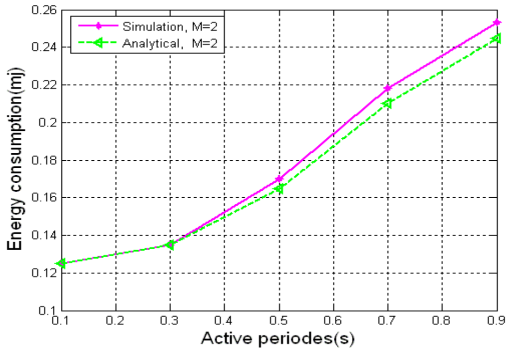

Fig.2 Average energy consumption

Also it shows the variation of energy consumption between simulation and analytical model as 3% only. Moreover, energy consumption of the sensor node's are due to the data packets forwarding and or receiving and it is much lesser than the total energy expenditure in the ideal mode. Hence, the punch of *G* is small. Lower level of data delivery delay at higher time period, awaken the sensor nodes by means of the active periods are higher rate and compares to the sleep state as shown in the Fig.3. Considering, *M =2, 5* and *G = 0.9.* As expected, the data delivery delay is very much less since several routes are available, i.e., *M =5.*

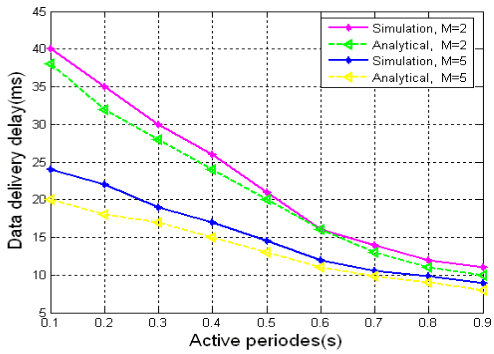

Fig.3 Average data delivery delay

However, the data delivery delay increases when the distance from the sink node increases and there is an increase in network traffic load. The time periods of active and sleep mode is almost equal to the value of 0.1 and *M = 5*, from the sink for *G= 0.4,0.9* as shown in the Fig. 4. When we fix the value of *G* as a constant, some of the sensor nodes are experiencing a smaller delay in data delivery than other nodes that are closer to sink node. Fig. 5 provides the average data delivery delay with respect to average wake-up intervals of different time periods. From this figure, it is observed that the data delivery delay increases with increasing of time intervals between the active and sleep state at the route value *M =2, 5*.

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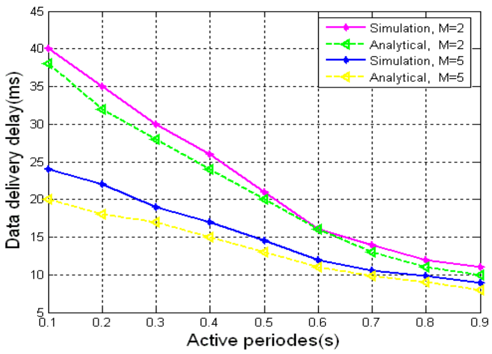

Fig. 4 Data delivery delay Vs distance

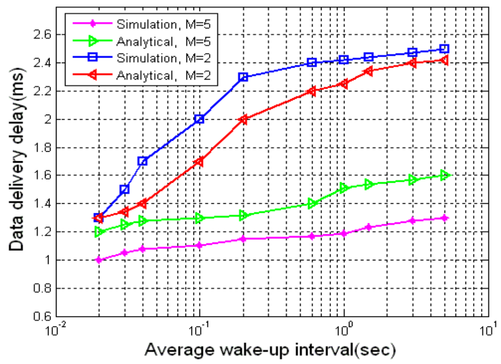

Fig. 5 Data delivery delay Vs wake-up (different) intervals

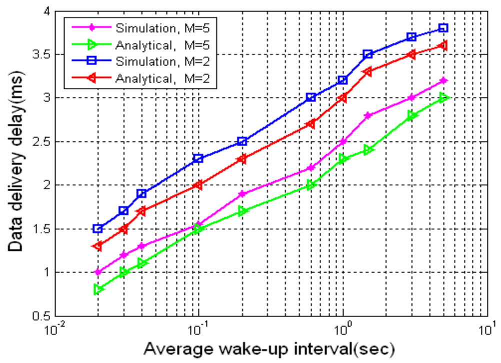

Fig. 6 Data delivery delay Vs wake-up (same) intervals

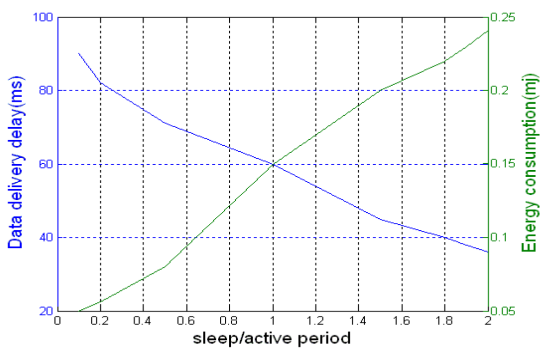

Fig. 7 Delay and Energy Trade-off

When $M = 5$, the delay is minimum value as compares with maximum value when $M = 2$ as shown in the Fig.6. In this case, time interval between active and sleep mode of operation is equal. Finally, Fig.7 shows the interesting and useful combination between energy consumption and data delivery delay. It is observed that, in the wireless sensor network the maximum number of sensor nodes at a particular time period is strictly related to the value of sleep/active nodes. For instance, let *sleep/active =1* ,which means that an average number of nodes are in active and sleep mode. For the lower values of sleep/active, shows less energy expenditure ,but the delay in data delivery is very large. When the values of sleep/active is greater than *1*, the delay in data delivery is minimum where as there is an increase in energy consumption.The value of *sleep/active=1* is the normalized point value and the further investigation on the sleep/active value has a greater impact on the delay in data delivery.

VII. CONCLUSION

In this research work a network with multihop transmission, which take place between the source and neighbor sensor nodes closer to the sink node is considered. Sensor nodes are operating under opportunistic protocol between sleep and active mode of operation. Data delivery delay and energy- efficiency of wireless sensor networks using asynchronous sleep-active scheduling is considered. Also studied and described the trade-offs between data delivery delay and energy consumption, in order to maximize the life time of sensor nodes and as well as improving the reliability of data delivery at the sink node. At the normalized point the data delivery delay is 60ms and the energy consumption is 0.15mJ. Comparison of simulation results gives a better agreement with the analytical results. It is observed that the variation of energy consumption between simulation and analytical model is 3% only.

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