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Adaptive and Efficient MAC Protocol in WSN

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Abstract—A WSN communicates over a short distance through wireless channels for information sharing and cooperative processing to accomplish a common task. WSNs can be deployed on a global scale for environmental monitoring and habitat study, over a battlefield for military surveillance and reconnaissance, in emergent environments for search and rescue, in factories for condition based maintenance and process control, in buildings for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring. In CSMA a node that has data to send, senses the common channel at first: if it is idle it transmits, otherwise, it attempts again after a random time. Collision Detection (CSMA/CD) was then added, to detect collisions during transmissions, stopping them and attempt again later. CSMA/CD is still not optimal in case of charged network, when a lot of collisions can occur. The main weakness of CSMA/CD is that it does not solve the problem of the hidden and the exposed terminals. In this research work the MAC is modified to behave adaptive. In the modified MAC, if destination is directly achievable from source then the Markov chain model will be used to transmit the data from source to destination. Else the modified MAC will select an agent according to the characteristics of the node. In other work the agent used will depend upon the node that transmits the data. The data is travelled from source to destination in multi-hop that is formed by unicast routing. The unicast procedure will select a neighbor to transmit the data that further transfer the data to its neighbor until data is reached to destination. The simulation result analysis shows that the performance of the proposed protocol is better than the existing protocol. The E2Edelay gets decreased and it results in enhanced throughput. The decreased delay and enhanced throughput confirms the better performance of the proposed protocol. The better performance is verified by the packet delivery ratio of the proposed protocol. The PDR of the proposed protocol is also better than the existing protocol.

Keywords— Wireless Sensor Network, MAC Protocol, Markov Model, IEEE 802.11,CSMA/CD.

I. INTRODUCTION

Wireless Sensor Networks is a specialized wireless network made up of a large number of sensors and at least one base station. The foremost difference between the WSN and the traditional wireless networks is that sensors are extremely sensitive to energy consumption. Energy saving is the crucial issue in designing the wireless sensor networks [1]. Since the radio transmission and reception consumes a lot of energy, one of the important issues in wireless sensor network is the inherent limited battery power within network sensor nodes. In order to maximize the lifetime of sensor nodes, it is preferable to distribute the energy dissipated throughout the wireless sensor network. So it is essential to design effective and energy aware protocols in order to enhance the network lifetime. WSN can have network structure based or protocol operation based routing protocol.

Energy consumption and network life time has been considered as the major issues wireless sensor network (WSN) requires an enormous breadth of knowledge from an enormous variety of disciplines, so its study becomes challenging [2]. Energy efficiency is a main challenge in wireless sensor networks and energy use is dominated by the energy required. In wireless sensor networks the size and cost of the sensor nodes may vary from micro to macro and from one to few hundred dollars respectively. Battery power decides whether the sensor nodes sense for long time or for short time even the battery cannot be recharged or replaced. Major sources of energy waste in wireless sensor network are basically of four types [3]:

A. Collision:

The first one is the collision. When a transmitted packet is corrupted due to interference, it has to be discarded and the follow on retransmissions increase energy consumption. Collision increases latency also.

B. Overhearing:

The second is overhearing, meaning that a node picks up packets that are destined to other nodes.

C. Packet Overhead:

The third source is control packet overhead. Sending and receiving control packets consumes energy too and less useful data packets can be transmitted.

D. Idle listening:

The last major source of inefficiency is idle listening i.e., listening to receive possible traffic that is not sent. This is especially true in many sensor network applications. If nothing is sensed, the sensor node will be in idle state for most of the time. The main goal of any MAC protocol for sensor network is to minimize the energy waste due to idle listening, overhearing and collision.

II. MAC LAYER PROTOCOLS

MAC is an important technique that enables the successful operation of the network. One fundamental task of the MAC protocol is to avoid collisions from interfering nodes. There are many MAC protocols that have been developed for wireless voice and data communication networks. Typical examples include the time-division multiple access (TDMA), code-division multiple access (CDMA), and contention-based protocols like IEEE 802.11 [4].

To design a good MAC protocol for the wireless sensor networks, we have considered the following attributes. The first is the energy efficiency. Sensor nodes are likely to be battery powered, and it is often very difficult to change or recharge batteries for these nodes. In fact, someday we expect some nodes to be cheap enough that they are discarded rather than recharged. Prolonging network lifetime for these nodes is a critical issue. Another important attribute is scalability and adaptivity to changes in network size, node density and topology. Some nodes may die over time; some new nodes may join later; some nodes may move to different locations[4,5]. A good MAC protocol should gracefully accommodate such network changes. Other typically important attributes including fairness, latency, throughput, and bandwidth utilization may be secondary in sensor networks. A wide range of MAC protocols defined for sensor networks are described briefly by stating the essential behavior of the protocols wherever possible. The medium access control protocols for the sensor networks can be classified broadly into two categories: Contention based and Schedule based.

III. IEEE 802.11 MAC SCHEME

The IEEE 802.11 specifies two modes of MAC protocol: distributed coordination function (DCF) mode (for ad hoc networks) and point coordination function (PCF) mode (for centrally coordinated infrastructure-based networks)[6]. The DCF in IEEE 802.11 is based on CSMA with Collision Avoidance (CSMA/CA), which can be seen as a combination of the CSMA and MACA schemes. The protocol uses the RTS–CTS–DATA–ACK sequence for data transmission.

Not only does the protocol use physical carrier sensing, it also introduces the novel concept of virtual carrier sensing. This is implemented in the form of a Network Allocation Vector (NAV), which is maintained by every node. The NAV contains a time value that represents the duration up to which the wireless medium is expected to be busy because of transmissions by other nodes. Since every packet contains the duration information for the remainder of the message, every node overhearing a packet continuously updates its own NAV. Time slots are divided into multiple frames and there are several types of inter frame spacing (IFS) slots. In increasing order of length, they are the Short IFS (SIFS), Point Coordination Function IFS (PIFS), DCF IFS (DIFS) and Extended IFS (EIFS). The node waits for the medium to be free for a combination of these different times before it actually transmits. Different types of packets can require the medium to be free for a different number or type of IFS. For instance, in ad hoc mode, if the medium is free after a node has waited for DIFS, it can transmit a queued packet. Otherwise, if the medium is still busy, a backoff timer is initiated. The initial backoff value of the timer is chosen randomly from between 0 and CW-1 where CW is the width of the contention window, in terms of time-slots. After an unsuccessful transmission attempt, another backoff is performed with a doubled size of CW as decided by binary exponential backoff (BEB) algorithm. Each time the medium is idle after DIFS, the timer is decremented. When the timer expires, the packet is transmitted. After each successful transmission, another random backoff (known as post-backoff) is performed by the transmission-completing node. A control packet such as RTS, CTS or ACK is transmitted after the medium has been free for SIFS [6].

IV. EXISTING MAC PROTOCOL

In CSMA a node that has data to send, senses the common channel at first: if it is idle it transmits, otherwise, it attempts again after a random time. Collision Detection (CSMA/CD) was then added, to detect collisions during transmissions, stopping them and attempt again later. CSMA/CD is still not optimal in case of charged network, when a lot of collisions can occur. The main weakness of CSMA/CD is that it does not solve the problem of the hidden and the exposed terminals [6,7].

Each time a new frame is generated at the network layer, it is inserted in the transmission queue where it waits to be served by the MAC protocol. This is the queue waiting time. The time between the instant the MAC protocol starts to serve the frame until the time it is ready to serve another one is named virtual service time (the term virtual is used because of the influence of the pos-transmission backoff which extends the real service time) [7] . Total time is the sum of these two times. When the MAC layer receives a request to transmit a frame, it starts running the algorithm illustrated in Figure 1 (the execution starts from the shadowed decision box). The standard [9] defines one initial backoff (pre-backoff) before the frame transmission, and another one when the transmission finishes (pos-backoff). For consecutive transmissions, the pos-backoff of the k-1 frame is applied as a pre-backoff of the k frame replacing the real pre-backoff. Thus for consecutive frame transmissions only one backoff contention is applied during the virtual service time, and the station will be only at the states 1, 2 and 3. For a new frame arriving on an empty queue, if the last pos-backoff has expired, the virtual service time will be composed by prebackoff, transmission and pos-backoff (MAC can be in states 4, 5, 2 or 3). For a unicast transmission, when a backoff is started the MAC selects uniformly a backoff value from the interval$(0, -1)$ Wi , where Wi is the current backoff stage contention window size. The backoff counter (BC) is decremented each time the channel is detected to be idle for an interval of a slot time. I.e., when busy slots are sensed, the BC is frozen. It is only decremented again after the channel is idle for a DIFS time interval (equals to 2.5 slots).

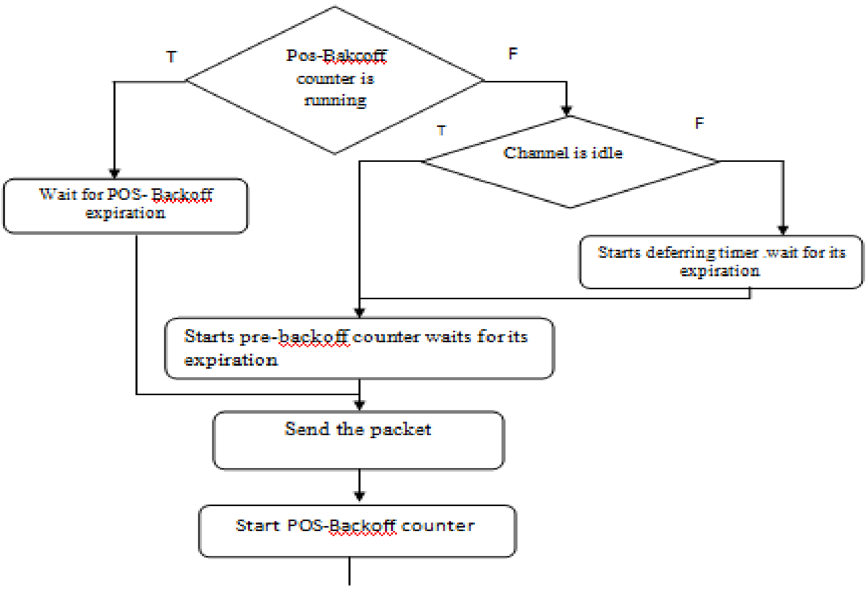

Figure 1: IEEE 802.11 MAC Algorithm To Transmit A Frame.[7]

A 2-way handshaking (basic mode) or a 4-way handshaking (RTS/CTS) can be used, depending on the frame's size to transmit. The backoff mechanism uses multiple backoff stages for a unicast transmission. When the BC expires at a given stage, the station tries a new transmission. As data transmission is acknowledged, a station retransmits the frame if the acknowledge is not received. When a retransmission is made, a station doubles the backoff window size, except for the last stage of backoff. If the retransmission at the last backoff stage is unsuccessful, the frame is discarded. For a broadcast transmission, only a single stage of backoff is used. When the BC expires, the data is sent without being acknowledged, which can lead to unrecoverable collisions if one or more stations start transmitting on the same slot [7].

V. MARKOV CHAIN MODEL

The network is further assumed to operate under acknowledged, unsaturated traffic conditions. The system is fully described by three stochastic processes, namely, the backoff stage at time t (s(t)), the state of the backoff counter at time t (c(t)), and the state of the retransmission counter at time t (r(t)). For the Markov chain to be applicable, it is assumed that nodes start sensing the medium independently. With these assumptions in mind, a 3-dimentional Markov chain results. It can be described by the tuple (s(t), c(t), r(t)). Assuming the stationary distribution of the Markov chain to be $b_{i,k,j} = \log_{t\to\infty} P(s(t) = i, c(t) = k, r(t) = j$, where , i∈(-2,m) $k \in (-1, \max(W_i - 1, L_s - 1, L_c - 1))$ and j∈ (0,n), a closed form formulae can be derived for this distribution chain. These derivations are tedious and the interested reader is referred to [4] for full derivations. It is worth mentioning that to reduce the complexity of the resulting formulae, Park applied some approximations such that the final mathematical system becomes implementable on sensor nodes. We now list the approximated formulae of Park's model that are of interest to us, and then we explain their significance:

where, The parameters L_s, L_{ACK} andL_s are the duration of successful transmission, the ACK packet, and the duration of packet collision, respectively. Furthermore, W_0 is the smallest backoff window defined in the standard to be$2^{macMinBE}$, m is set to macMaxCSMABackoffs and n is set to macMaxFrameRetrie. Finally, the probabilities α, β and P_C represent the probability of finding $CCA1$[1] busy, the probability of finding CCA2 busy, and the probability of collision, respectively [10].

$$\sum_{i=0}^{m}\sum_{k=0}^{W_i-1}\sum_{j=0}^{n} b_{i,k,j} + \sum_{i=0}^{m}\sum_{j=0}^{m} b_{i,-1,j} + \sum_{j=0}^{n}\left(\sum_{k=0}^{L_s-1} b_{-1,k,j} + \sum_{k=0}^{L_c-1} b_{-2,k,j}\right) + \sum_{l=0}^{L_0-1} Q_l = 1 \quad (1)$$

$$\sum_{i=0}^{m}\sum_{k=0}^{W_i-1}\sum_{j=0}^{n} b_{i,k,j} \approx \frac{b_{0,0,0}}{2}[(1+2x)W_0 + 1 + x](1+y) \quad (2)$$

$$\sum_{i=0}^{m}\sum_{k=0}^{W_i-1}\sum_{j=0}^{n} b_{i,k,j} \approx b_{0,0,0}(1-\alpha)(1+x)(1+y) \quad (3)$$

$$\sum_{j=0}^{n}\left(\sum_{k=0}^{L_s-1} b_{-1,k,j} + \sum_{k=0}^{L_c-1} b_{-2,k,j}\right) \approx b_{0,0,0} L_s (1 - x^{m+1})(1+y) \quad (4)$$

$$\sum_{l=0}^{L_0-1} Q_l \approx b_{0,0,0}\frac{1-\lambda}{\lambda} L_0[1 + y + P_c(1 - x^{m+1})(y^n - y - 1)] \quad (5)$$

$$\tau \approx (1+x)(1+y) b_{0,0,0} \quad (6)$$

Where

$$x = \alpha + (1-\alpha)\beta \quad (7)$$

$$y = P_c(1 - x^{m+1}) \quad (8)$$

$$\alpha = L P_c(1-\alpha)(1-\beta) + L_{ack}\frac{N\tau(1-\tau)^{N-1}}{1-(1-\tau)^N} P_c(1-\alpha)(1-\beta) \quad (9)$$

$$\beta = \frac{P_c + N\tau(1-\tau)^{N-1}}{2-(1-\tau)^N + N\tau(1-\tau)^{N-1}} \quad (10)$$

$$P_c = 1 - (1-\tau)^{N-1} \quad (11)$$

The state Q is the idle state during which no packets are available for transmission. This state is modeled as $Q_i(where\ i = 0,1, \dots \dots L_0 - 1$ to show that it has a duration specified by L_0. Q_i models the unsaturated traffic condition.

Equation (1) is the normalization condition. The first term in this equation represents the probability of being in a backoff state. The second term refers to the probability of initiating CCA2. The third and fourth terms refer to the packet transmission state and packet collision state, respectively. Finally, the fifth term refers to the probability of being in the idle state when no packets are available. Equations (2)-(5) provide the mathematical expressions for all of these terms. Equations (2)-(5) can be directly used to find an expression for $b_{0,0,0}$.[10]

VI. PROPOSED WORK

In the proposed work the MAC is modified to behave adaptive. In the modified MAC, if destination is directly achievable from source then the Markov chain model will be used to transmit the data from source to destination. Else the modified MAC will select an agent according to the characteristics of the node. In other work the agent used will depend upon the node that transmits the data. The data is travelled from source to destination in multi-hop that is formed by unicast routing. The unicast procedure will select a neighbor to transmit the data that further transfer the data to its neighbor until data is reached to destination. The complete process can be explained by following algorithm:

VII. PROPOSED ALGORITHM:

The source node will send route request to the destination.
If destination is at one hop distance then apply MARKOV model to transfer the data
Else
Intermediate nodes receiving the request will forward the request to adjacent node
Analyze the characteristics of current node i.e. energy , number of neighbor, nearest neighbor distance, sensing range, Wait time, Back counter value.
Decide agent based on analyzed characteristics i.e. MAC, AGT, PHY.
Wait for Pre-Backoff time then transfer the data
The step 3-7 is repeated until destination found.
The above algorithm used the different agent to transmit the data ; it must enhance the performance of the network. It can be represented as follow:

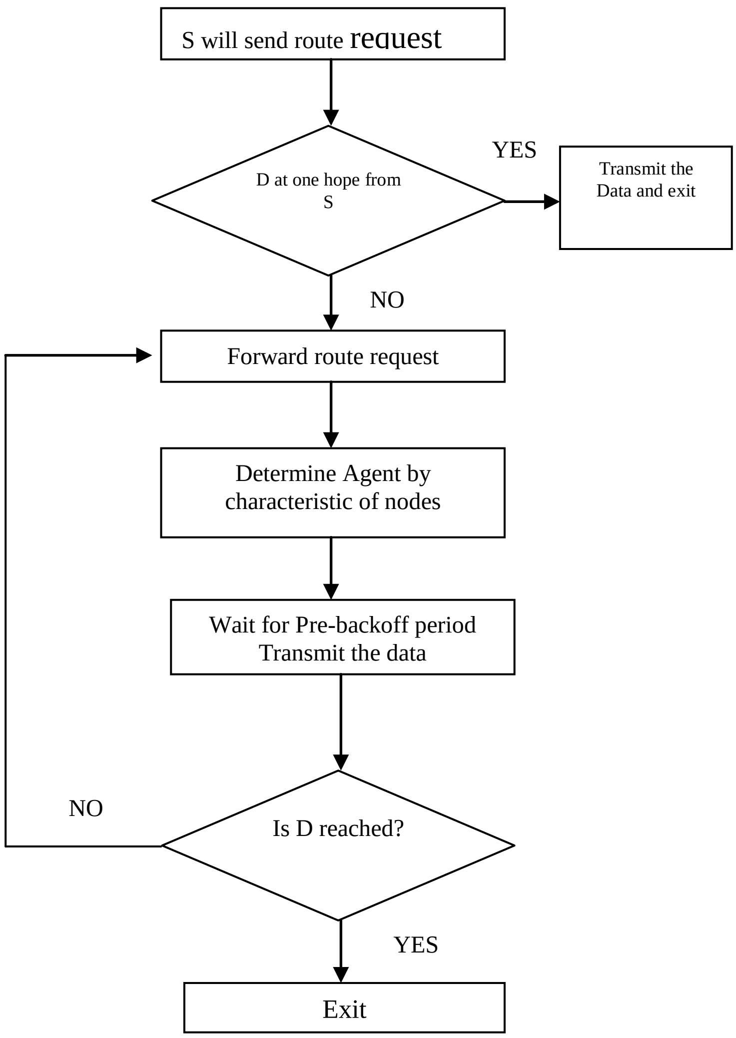

Figure 2: Proposed Flowchart

VIII. IMPLEMENTATION

The research work implements the proposed protocol by using NS2.35. When we run the TCL file then it creates the TR file. The AWK scripts are used to evaluate various parameter .The AWK script use the TR file to get result. The parameter evaluated by running AWK scripts on the TR file generated by TCL file are shown in following tables.

Parameter Analysed

Packet Delivery Ratio (PDR): The number of delivered data packet ratio to the destination and this also illustrates the level of delivered data to the destination.

∑ Number of packet receive / ∑ Number of packet send

End-to-end Delay: The average time taken by a data packet to arrive in the destination and it also includes the delay caused by route discovery process and the queue in data packet transmission and only successfully data packets that delivered to destinations that counted.

∑ (arrive time – send time) / ∑ Number of connections

Throughput: Throughput or network throughput is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

Table 1: Performance Analysis of Existing Algorithm

Number of nodes	**PDR**	**E2edelay**	**Throughput**
50	95.40	0.3821	249.644
100	93.45	0.7587	123.169
150	89.40	1.0827	82.5732
200	87.14	1.3841	62.9563

Table 2: Performance Analysis Of Proposed Algorithm

Number of nodes	**PDR**	**E2edelay**	**Throughput**
50	100	0.0108	9124.25
100	100	0.0122	8167.09
150	100	0.0114	8715.4
200	100	0.0151	6605.94

In next section the above parameters are shown graphically. These are as follows: figure 3 shows the Packet Delivery Ratio between the existing and proposed algorithm. Next graph figure 4 shows the e2e delay and figure 5 shows the throughput between existing and proposed.

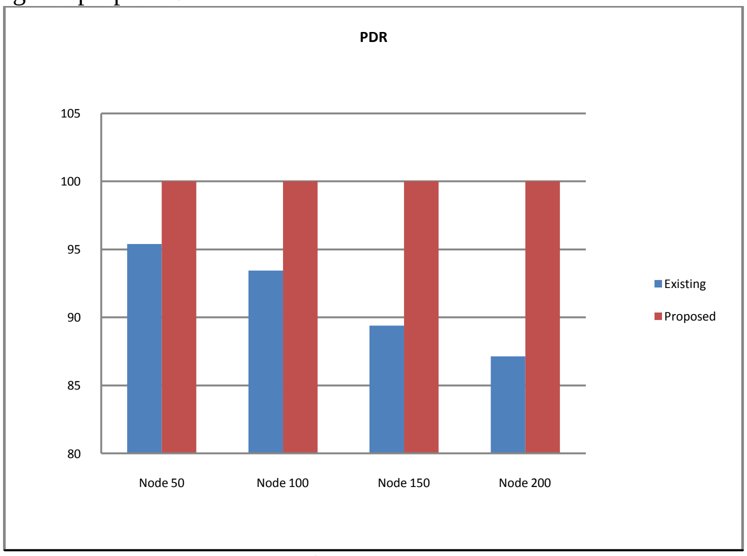

Figure 3: Comparison of PDR between Existing and Proposed

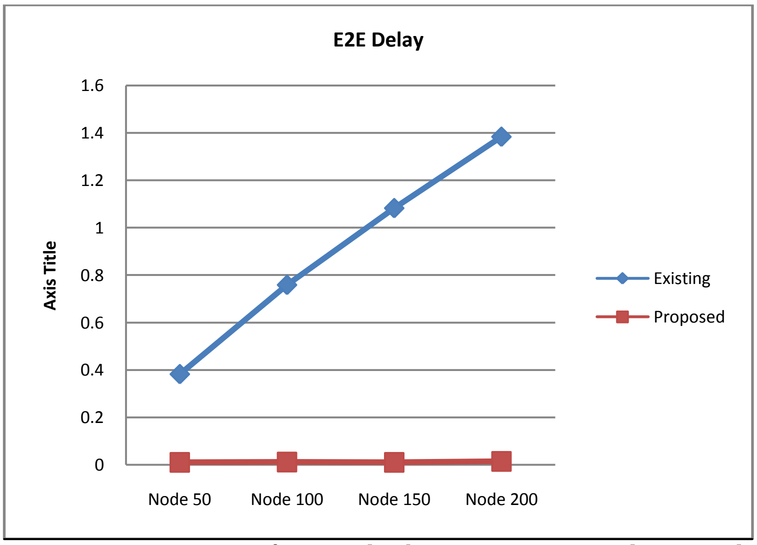

Figure 4: Comparison of E2E Delay between Existing and Proposed

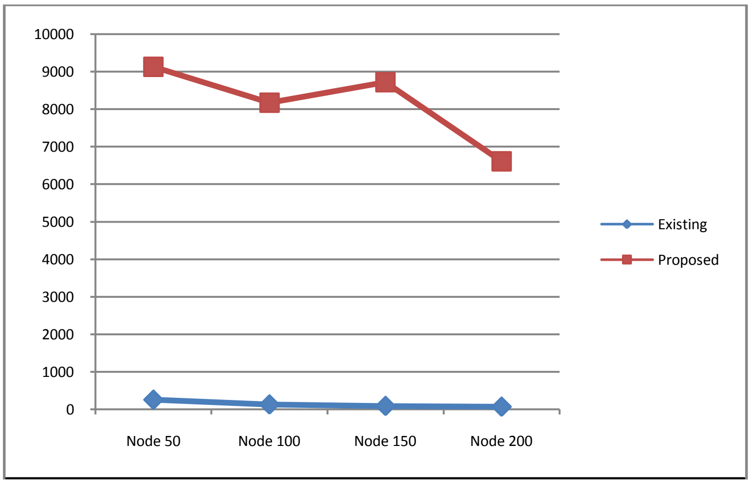

Figure 5: Comparison of Throughput between Existing and Proposed

The graphical and the tabular analysis show that the performance of the proposed protocol is better than the existing protocol. The E2Edelay gets decreased and it results in enhanced throughput. The decreased delay and enhanced throughput confirms the better performance of the proposed protocol. The better performance is verified by the packet delivery ratio of the proposed protocol. The PDR of the proposed protocol is also better than the existing protocol.

IX. Conclusions

In this research work the MAC is modified to behave adaptive. In the modified MAC, if destination is directly achievable from source then the Markov chain model will be used to transmit the data from source to destination. Else the modified MAC will select an agent according to the characteristics of the node. In other work the agent used will depend upon the node that transmits the data. The data is travelled from source to destination in multi-hop that is formed by unicast routing. The unicast procedure will select a neighbor to transmit the data that further transfer the data to its neighbor until data is reached to destination. The adaptive MAC is compared with existing MAC by varying the number of nodes in the scenario. The implementation is done by using the NS2 simulator. The simulation result analysis shows that the performance of the proposed protocol is better than the existing protocol. The E2Edelay gets decreased and it results in enhanced throughput. The decreased delay and enhanced throughput confirms the better performance of the proposed protocol. The better performance is verified by the packet delivery ratio of the proposed protocol. The PDR of the proposed protocol is also better than the existing protocol. In future following work can be done: The adaptive MAC can be analyzed on different topology based network., The adaptive MAC can be applied to other standard of MAC i.e. 802.15.4.

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