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Minimization of Collision in Energy Constrained Wireless Sensor Network

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Abstract

Wireless Sensor Networks (WSNs) are one of the fastest growing and emerging technologies in the field of Wireless Networking today. The applications of WSNs are extensively spread over areas like Military, Environment, Health Care, Communication and many more. These networks are powered by batteries and hence energy optimization is a major concern. One of the factors that reduce the energy efficiency of the WSN is collision which occurs due to the high density of data packets in a typical communication channel. This paper aims at minimizing the effects of congestion leading to collision in the network by proposing an effective algorithm. This can be done by optimizing the size of the contention window by introducing parameters like source count and α. If the contention window of a node is low, it results in collision. If the size of the contention window of a node is high then it results in a medium access delay. Thus minimizing collision and medium access delay of data packets conserve energy.

Keywords: Energy, Collision, Contention Window, Wireless Sensor Networks

1. Introduction

Wireless Sensor Networks (WSNs) are a typical type of wireless networks consisting of a large number of sensor nodes. WSNs are undoubtedly one of the largest growing types of networks today. They are fast becoming one of the largest growing networks today and, as such, have attracted quite a bit of research interest. They are used in many aspects of our lives including environmental analysis and monitoring, battlefield surveillance and management, emergency response, medical monitoring and inventory management. These networks also play a significant role in areas like agriculture and industries as well. Their reliability, cost-effectiveness, ease of deployment and ability to operate in an unattended environment, among other positive characteristics, make sensor networks the leading choice of networks for these applications.

Much research has been done to make these networks operate more efficiently including the application of data aggregation. A wireless network normally consists of a large number of distributed nodes that organize themselves in an ad-hoc fashion. Each node has one or more sensors, embedded processors and low power radios which are normally battery operated. Unlike other wireless networks, it is generally difficult or impractical to charge/replace exhausted batteries. That is why the primary objective in wireless sensor networks design is maximizing node/network lifetime, leaving the other performance metrics as secondary objectives. Various factors like concurrent transmissions, buffer overflows and dynamically time varying wireless channel conditions lead to the concept of Congestion [1]. Collision has the following drawbacks: 1) increase energy dissipation rates of sensor nodes, 2) causes a lot of packet loss, which in turn diminish the network throughput and 3) hinders fair event detections and reliable data transmissions [2,3]. Congestion control or congestion avoidance has thus become very crucial for effective transmission of data packets [4]. The main reason of congestion in WSN, is allowing sensing nodes to transfer as many packets as they can [2]. Hence it can be inferred that, congestion in wireless networks leads to collision between the packets transmitted. Collision occurs when two nodes send data at the same time, over the same transmission medium or channel. Medium Access Control (MAC) Protocols have been developed to assist each node to decide when and how to access the channel [1–10]. However, the medium- access decision within a dense network composed of nodes with low duty-cycles is a challenging problem that must be solved in an energy-efficient manner. Keeping this in mind, emphasis is first given to the peculiar features of sensor networks, including reasons for potential energy wastage at medium-access communication and how they can be minimized.

2. Priority Based MAC Protocol

2.1. Configuration Requirements

First the topology of the entire Wireless Sensor Network (WSN) is set as required. The MAC type used here is 802.11. For transmission and reception of data packets to take place in a WSN, there is a need to have a source node, the transmission paths to be followed, and a sink node. Source nodes can vary but sink nodes are fixed once the transmission of data packets occur. The final collection of the transmitted data occurs at the sink node. This collected data is taken and used according to the application needed. Apart from this various other parameters like transmission range, packet size, sink location, data rate, simulation time and initial energy are all given as initial settings along with the topology formation.

2.2. Calculation of Sensing Nodes (Ns)

N_s is the approximate number of nodes within the sensing radius of a particular event. We consider a network of N sensing nodes, deployed with uniform random distribution over an area A. The Node density is defined as $\rho = N/A$. And N_s is calculated as,

$$N_s = \pi \ \rho \ R_s^2 \tag{1}$$

where, R_s is the sensing range of each node. A single sink node in the network placed anywhere within the terrain is taken into consideration. Mobile sensors which form a dynamic ad-hoc network are not considered. All sensing nodes considered are static and the network is homogeneous i.e., all nodes have the same processing power and equal sensing and transmission range. Data generation rate of each sensing node is also assumed to be equal.

2.3. Priority Based Source Count

Source Count value of any node i, denoted as SC_i, is defined as the total number of nodes to which it is able to forward data. In other words, it is the number of downstream nodes for a particular node, which responds to the advertisement of the node. Since a downstream node requires knowing its Source Count (SC) value whenever it has some data packets to send, it is sufficient to propagate SC value along with the data packet. While transmitting data packets, each upstream node inserts its SC value in the packet header and the downstream node can easily obtain its SC value. An upstream node learns the SC value of its downstream by snooping packets transmitted by the latter. Note that, a transient state exists between the event occurrence and the stabilization of SC values of all downstream nodes. SC value of a downstream node is stabilized whenever it receives at least one packet from all of its upstream nodes and therefore the network enters into steady state when the sink node receives at least one packet from each source node. Since the duration of transient state is very short (less than a second in our simulation), the effectiveness of the proposed protocol is not hampered. It is notable that, SC values of each node along the routing path are updated without transferring any additional control packets. This SC parameter works as a driving entity for all schemes of our proposed protocol. Thus the SC values for all the nodes that are involved in transmission and receptions of data packets are calculated. With the help of these values the priority of transmission is assigned to each node. This helps in minimizing the collision in the Wireless Sensor Network.

2.4. Calculation of Contention Window

Contention Window is a parameter which depends on time [1]. It determines the rate of flow of data packets and medium access delay. Now the Contention Window value is calculated for each node that is involved in the communication process. It is calculated as follows:

$$W\ (i) = CWmin\ x\ (N_s/Sc_i\ ) \tag{2}$$

where, W (i)-Contention Window value for any node i, CWmin-Minimum Contention Window value, N_s- Approximate number of nodes within the sensing radius of a particular event, Sc_i-Source Count value of any node i.

2.5. Inclusion of α Parameter

The parameter α is a scaling factor that is introduced in Equation (2) to optimize effects of collision and medium access delay. It ranges from 0.1 to 2 based on channel contention.

$$W\ (i) = CWmin\ x\ (N_s\ /\ Sc_i\ )\ x\ (1/\ \alpha\ ) \tag{3}$$

If the number of contending neighbors of a transmitting node is very low, lower value of α simply increases the medium access delay and reduces the network throughput. On the other hand, if the number of contending neighbors of a transmitting node is very high, a higher value of α increases the collision probability and thereby increases packet loss. The value of α is initialized to 1, which nullifies its effect. Later on, to ensure efficient medium utilization, the value of α is set carefully. A sharp increase or decrease of the value of α may also hinder the throughput of the network. Sections 3.1 and 3.2 describe the variation of α.

2.6. Idealization of Contention Window

The limitation of Equation (2) is that the contention window cannot be varied for different number of data packets. But we know that window size is directly proportional to packet size and inversely proportional to data rate. Hence we have another equation:

W (i) = (Packet size x No. of data packets)/Data rate (4)

Equation (4), is used to vary the α value in Equation (3) and thereby an optimized contention window is obtained in order to minimize the effects of collision and delay, in the process of communication, simultaneously.

2.7. Idle Listening

In the above sections, the effect of collision and some parameters associated with it have been analyzed. In this section, another factor has been taken into account which leads to some amount of energy loss in MAC protocols - idle listening [11]. Since a node does not know when it will be the receiver of a message from one of its neighbors, it must keep its radio in receive mode at all times. So it loses energy as long as it is ON. Hence, the nodes which do not take part in the communication, loses energy due to idle listening. Here in this paper, this phenomenon has been considered in Sections 2.8 and 3.3. As a result, a particular amount of energy is conserved and better energy efficiency is obtained for each node in the network.

2.8. Evaluation with Idle Listening

In this paper, each node in the network is enabled when it receives or transmits data packets. If a node does not involve in communication, it is disabled, whereby no further transmission or reception of data packets take place. The amount of energy lost by keeping a node in the ON state is approximately 50–100% of the receiving energy. In the scenarios explained in Sections 3.1 and 3.2, the energy loss due to the node being in the ON state is 66% of the receiving energy. When the nodes that are not involved in the communication process are disabled, this energy is saved and we obtain higher energy efficiency.

3. Energy Analysis

In the above sections, we have discussed about the phenomenon of contention window and idle listening. In this section, we will discuss two scenarios in which the contention window is varied to consider the effects of collision and medium access delay.

3.1. Scenario 1

In the first scenario, we have eight nodes placed in a randomly chosen topology. The simulation would be carried out according to the parameters mentioned in the above table. Here we would consider the effect of collision for each node in the network.

Using the specifications given in Table 2, data packets are transmitted. Here the data packets are very high in number and so when they are transmitted, collision occurs. In order to minimize the collision, we vary the contention window by decreasing α value. By doing so the contention window size is increased and thereby collision is minimized. This variation of α is done by keeping the value of contention window obtained from Equation (3) as reference.

Table 1. Simulation parameters.

Parameter	*Value*
Total Area	500 x 500
Number of nodes	8
MAC Type	802.11
Initial Energy	5 Joule/Node
Transmission Energy	0.0005 Joule/Node
Reception Energy	0.0003 Joule/Node
ON-Time Energy	0.0002 Joule/Node
Data Rate	10 Bytes/s
Packet Size	64 Bytes
Initial α Value	1
Range of α Value	0.1 ~ 2
Simulation Time	150 ms

Table 2. Source count and No. of packets.

Node	*Source Count*	*No. Of Packets*
0	3	10
1	3	12
2	2	4
3	1	18
4	1	11
5	4	9
6	5	7
7	5	12

Using the specifications given in Table 2, data packets are transmitted. Here the data packets are very high in number and so when they are transmitted, collision occurs. In order to minimize the collision, we vary the contention window by decreasing α value. By doing so the contention window size is increased and thereby collision is minimized. This variation of α is done by keeping the value of contention window obtained from Equation (3) as reference.

Figure 1 is a diagrammatic representation which shows that, more number of data packets is sent within the limited time frame and as a result, collision is occurring.

$$\uparrow W(i) = Wmin \text{ x } (Ns/SCi) \text{ x } (1/\alpha)\downarrow \qquad (5)$$

3.2. Scenario 2

In the second scenario, we have eight nodes placed in a randomly chosen topology. The simulation would be carried out according to the parameters mentioned in Table 3. Here, the effect of medium access delay for each node in the network is considered. The number of packets transmitted by each node would be lesser than the number considered in the first case of collision.

Using the above specification, data packets are transmitted. Since they are very less in number medium access delay occurs. In order to minimize this delay, we vary the contention window by increasing the α value. By doing so the contention window size is decreased and thereby medium access delay is minimized. This variation of α is done by keeping the value of contention window obtained from Equation (3).

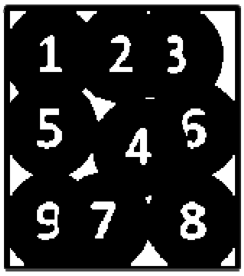

Figure 1. Collision of packets when contention window size is small.

Table 3. Source count and No. of packets.

Node	*Source Count*	*No. Of Packets*
0	3	2
1	3	2
2	2	3
3	1	6
4	1	6
5	4	1
6	5	1
7	5	1

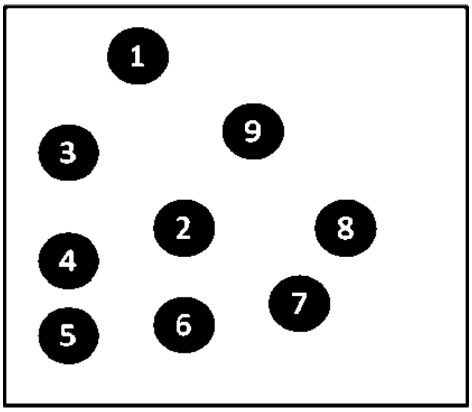

Figure 2. Medium access delay in the network when contention window size is large.

Figure 2 is a diagrammatic representation which shows that, less number of data packets is sent within the large time frame and as a result, medium access delay is occurring.

$$\uparrow W(i) = Wmin \text{ x } (Ns/SCi) \text{ x } (1/\alpha)\downarrow \qquad \textbf{(6)}$$

3.3. Conclusion of Energy Analysis

In Scenario 1, to minimize the effect of collision, the size of the contention window is increased by decreasing the α value. In Scenario 2, to minimize the effect of medium access delay, α value is increased. This results in minimizing the medium access delay.

Thus taking into account whether collision occurs or medium access delay occurs, α value is varied and thereby the contention window is also varied. Thus an idealized contention window required for the communication process is obtained which will minimize the effect of collision and medium access delay to a greater extent, producing high efficiency.

In the above 2 cases energy loss due to idle listening is reduced. This is achieved by disabling the nodes when transmission and reception of data packets do not occur. However, the energy conserved in the above scenarios was observed to be considerably less. Further analysis can be done on implementing a better algorithm to reduce the effect of idle listening.

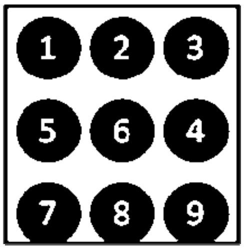

Figure 3. Optimized contention window in order to minimize both collision and medium access delay.

Figure 3 is a diagrammatic representation which shows the ideal condition that the data packets is sent within the idealized time frame and as a result collision and medium access delay is minimized to a great extent.

4. Results

Considering the above mentioned topology and simulation parameters two cases have been analyzed. In the first case the effect of collision has been minimized and in the second case, the phenomenon of medium access delay has been dealt with. Thus we try to obtain an ideal contention window size whereby both these effects are dealt with effectively. The implementation of the following scenarios have been done in Network Simulator-2 (Ns-2), version 2.28 [12].

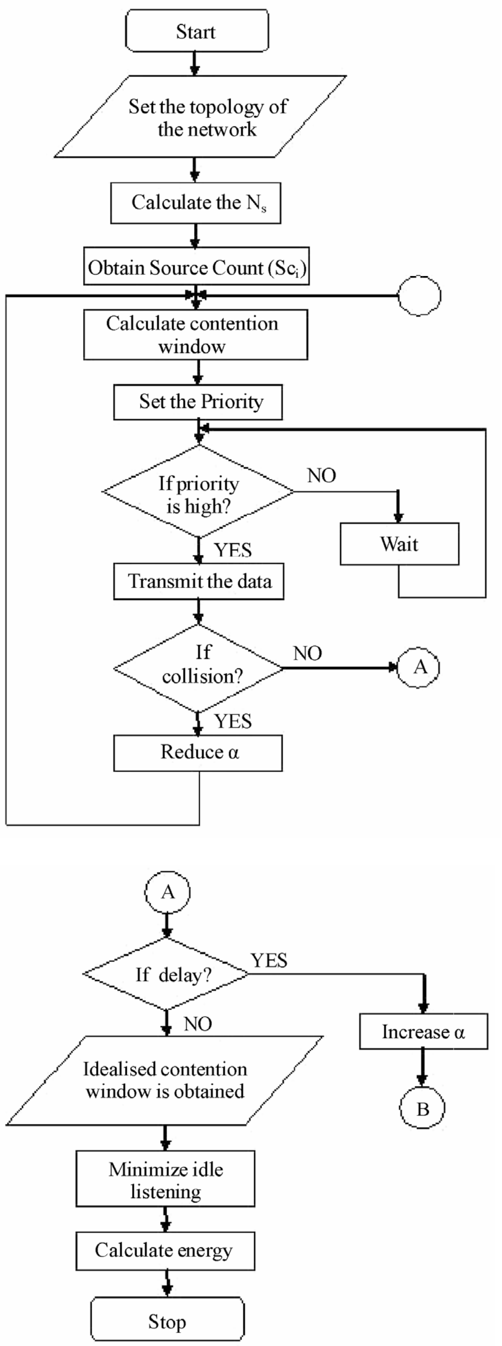

Figure 4. Flow-diagram which explains the flow of the entire process of the proposed protocol.

4.1. Scenario 1

Here in this scenario, consider that each node in the network has a higher number of packets to send to the downstream nodes in the network. Due to this, the contention window would be small and thus its size been increased. Thus it has been found that the collision is minimized effectively. As a result, the energy lost in each node has been reduced. Furthermore, a small amount of energy has been conserved by reducing idle listening.

It has been observed that, though the collision has been minimized, a very small medium access delay occurs with each node in the network.

Table 4. Results considering collision.

Node	Energy Remaining in Node			
	With-out SC	With SC	With SC & CW	With SC, CW and Idle listening
0	4.7049	4.7349	4.7899	4.7919
1	4.7329	4.7679	4.8329	4.8349
2	4.8634	4.9109	4.9159	4.9199
3	4.8574	4.8574	4.9324	4.9374
4	4.8384	4.8919	4.9219	4.9259
5	4.7529	4.7979	4.8479	4.8499
6	4.7849	4.8729	4.9129	4.9269
7	4.6874	4.8014	4.8714	4.8764

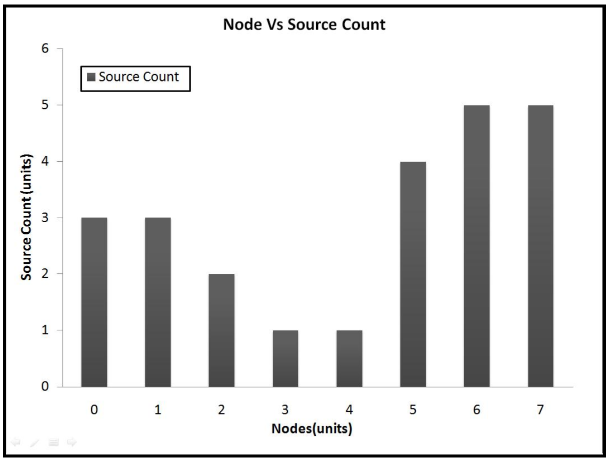

Figure 5. The source count value for each node.

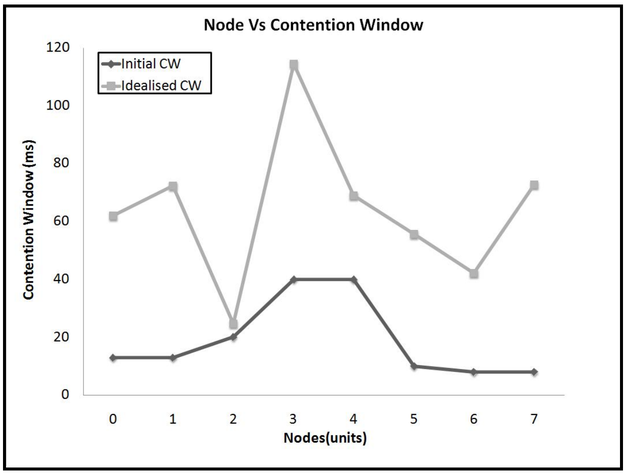

Figure 6. The initial contention window and idealized contention window for each node.

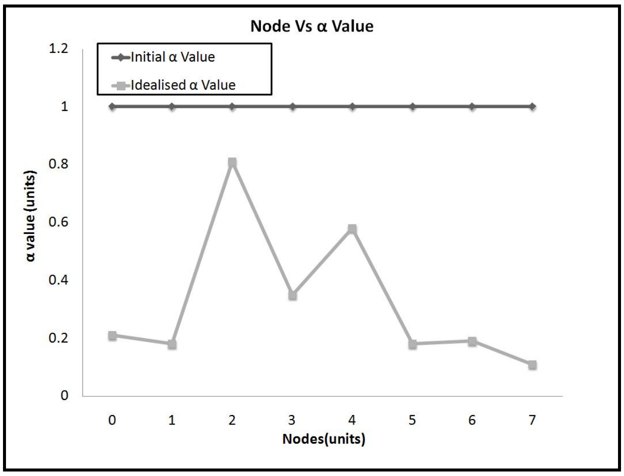

Figure 7. The *α* value which has been reduced due to the collision which occurs in each node.

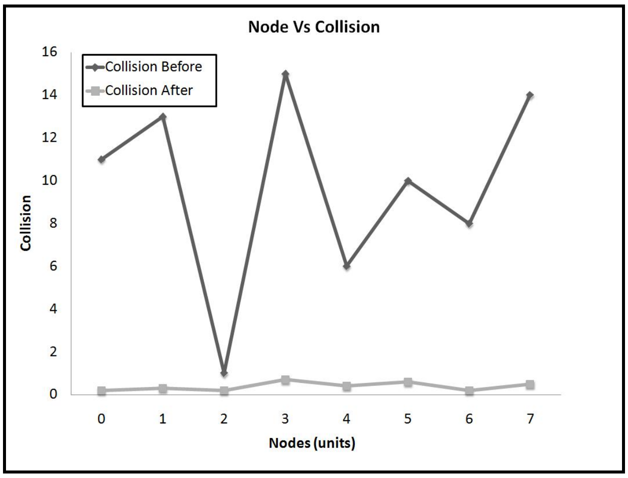

Figure 8. The collision occurring and the collision which has been minimized for each node.

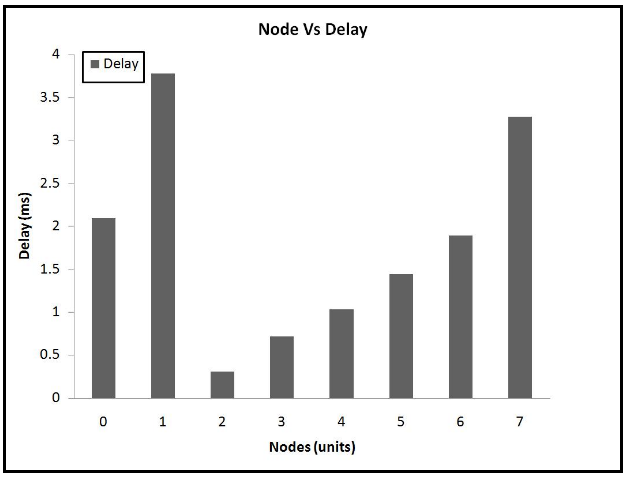

Figure 9. The delay occurring after obtaining the ideal size for the contention window for each node.

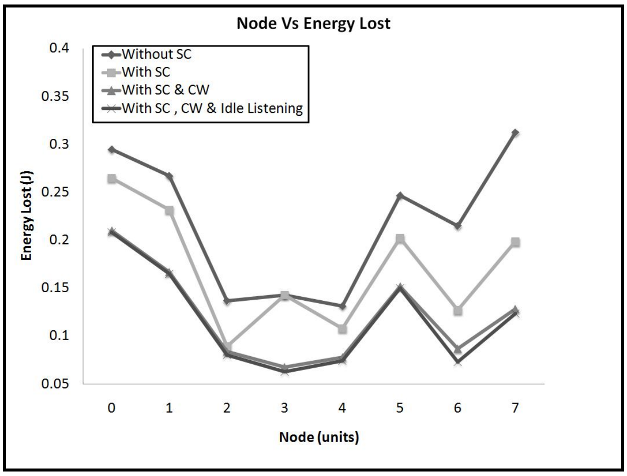

Figure 10. The energy lost comparison for each node after applying the various cases.

Table 5. Results considering medium access delay.

Node	Energy Remaining in Node			
	Without SC	With SC	With SC & CW	With SC, CW and Idle listening
0	4.7049	4.7899	4.7899	4.7919
1	4.7329	4.8329	4.8329	4.8349
2	4.8634	4.9159	4.9159	4.9199
3	4.8574	4.9329	4.9324	4.9374
4	4.8384	4.9219	4.9219	4.9259
5	4.7529	4.8479	4.8479	4.8499
6	4.7849	4.9129	4.9129	4.9269
7	4.6874	4.8714	4.8714	4.8764

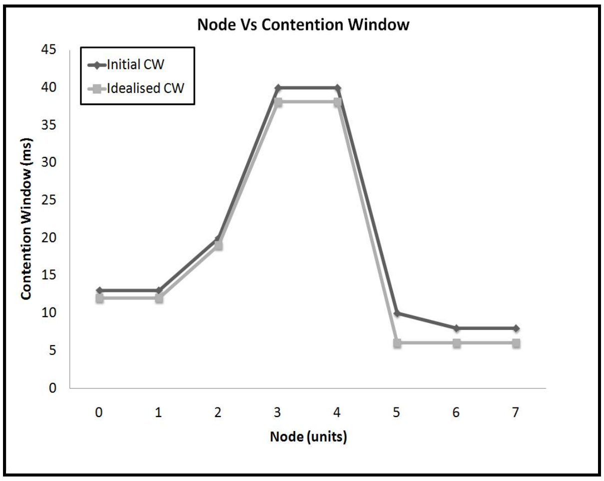

Figure 11. The graph above shows the initial contention window size and the idealized contention window for each node.

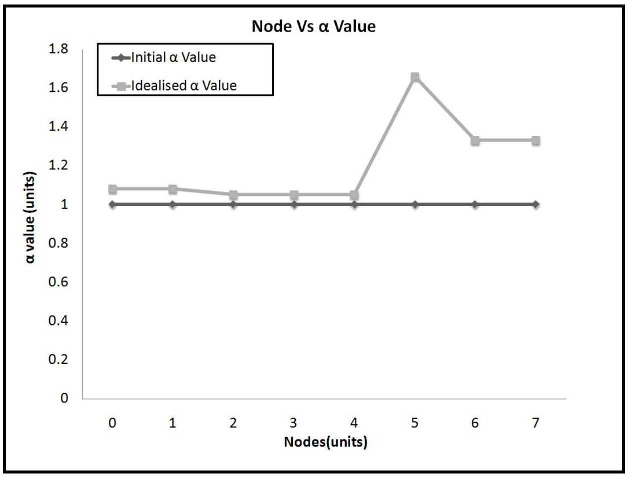

Figure 12. The *α* value which has been reduced due to the collision which occurs in each node.

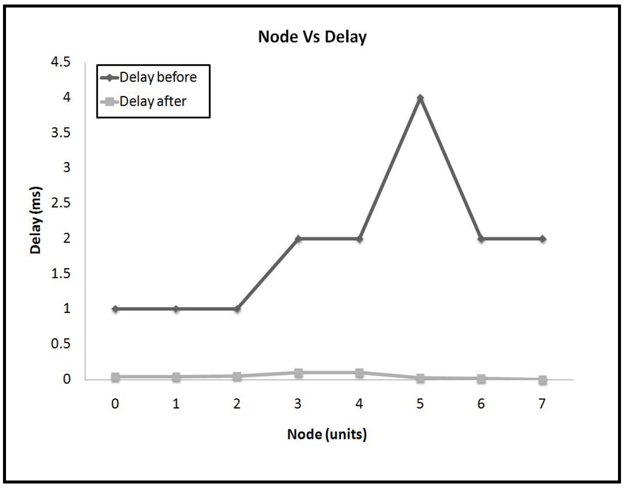

Figure 13. The graph above shows the initial delay and the minimized delay for each node.

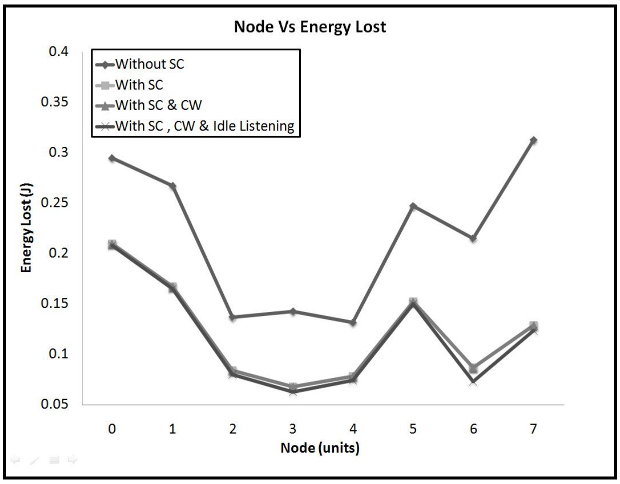

Figure 14. The energy lost comparison for each node after applying the various cases.

4.2. Scenario 2

In this scenario, consider that each node in the network has a smaller number of packets to send to the downstream nodes in the network. Due to this, the contention window would be larger than required and thus its size has been reduced. The contention window size is varied in such a way that the medium access delay becomes negligible and collision is avoided.

It has been observed that, medium access delay has been minimized and along with effects of collision. This has helped in increasing the throughput of the network. Furthermore the effect of idle listening and the energy loss caused by it has been dealt with.

5. Conclusions

In this paper, a novel method of minimization of collision and medium access delay is introduced to reduce the loss of energy of the nodes in the network. Here a Source Count value is considered for each node, in order to reduce the collision of packets in the network. The Source Count value prioritizes the transmission of packets from each node, whereby the collision of data packets and medium access delay associated with each node during communication process are minimized. The Contention Window size is calculated in accordance with Source Count values assigned for each node. The initial efficiency of the WSN was found to be around 70%. After applying the various parameters to minimize collision and medium access delay, the efficiency was increased to around 85-90%. Hence a substantial amount of energy can be saved through this method. Without optimizing on idle listening, the efficiency was found to be around 82%.

Though the idealized contention window size has been calculated, the chances of collision and medium access delay may still prevail in a minimal amount in the network. Hence it should be noted that a MAC protocol needs to be introduced which could eliminate the effects of collision and medium access delay simultaneously. Also the energy conserved by minimizing idle listening, can further be improved.

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