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TDMA and Data Aggregation Method for Energy Efficient Data Transmission in Automatic Irrigation System

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***Abstract* -Wireless sensor networks(WSN) find wide applications in environmental monitoring.MAC protocols play a vital role in controlling the energy consumption in a WSN. It tells the network when and how to access the medium. Time division multiple access (TDMA) is well suited for these real time applications. Because it prevents radio interference ,and reduces energy consumptions. In this paper a TDMA based MAC protocol is used to collect environmental data like moisture level and temperature of the soil in an irrigation system .Here the base station is collecting the data in a particular area using the sensor nodes which are deployed over there. All nodes in the network are homogenous and energy constrained. TDMA scheduler assigns the time slots for each node on which it can transmit data. The sensor nodes turn ON/OFF their radio according to the schedule to save energy. If the collected data is less than the threshold value ,base station will inform the controller by setting the corresponding bit in order to perform the motor control action. In this paper two methods based on TDMA scheduling is used. First one is a direct communication method , in which each node transmits the data directly to the sink. Second method uses data fusion (aggregation) method in which nodes are grouped into clusters and a considerable amount of energy is saved. The simulation results shows that the aggregation method is providing a 10 % of increase in the residual energy and 13 % of increase in the throughput.**

Keywords- TDMA scheduling, wireless sensor networks, energy efficiency, irrigation

I. INTRODUCTION

An agricultural country like India has been following the traditional methods for irrigation. These irrigation methods were able to meet the rapidly growing food requirements of the nation. But in majority of the case, the knowledge regarding the optimum conditions for a particular crop is not known to a farmer. This causes a huge loss in terms of utilization of land in our country. The nations with lesser agricultural area have shown a higher productivity in agriculture. The adoption and implementation of upcoming technology by these nations has taken them a long way ahead of us. Availability of energy is one of the important factors in the irrigation system. Stone et al. (1985) presented a computer-based monitoring system for continuous measurements of soil water potential. In village areas there is power shortage. For irrigation they mainly depend on rain. By incorporating suitable sensors and other surveillances from strategic points in large farms, it would be possible to monitor and control the conditions in it to obtain maximum productivity from the farm. It would help the farmers in a huge way by avoiding the money usually spent on labour to do the watering and fertilizing and at the same time reduce the monitoring load, which rests on them. This in turn will help increase productivity while reducing the costs involved.

This paper is basically on an automated irrigation system with electronic controls and monitoring that uses energy efficient Time Division Multiple Access (TDMA) methods for data transfer. It can be mainly divided into two; automatic irrigation system and an energy efficient wireless sensor network. Automatic irrigation is done with the help of 4 sensors and solenoid valves. The data given by the sensors are interpreted by microcontroller and it turns on both the mixer and motor according to the need of soil. The water-fertilizer composition is determined by microcontroller as it is programmed. Wireless sensor network (WSN) is an emerging technology that has a wide range of potential applications including environment monitoring, agriculture, vehicle monitoring, smart spaces, medical systems and robotic exploration etc. It can sense the physical conditions such as temperature, pressure, moisture, vibrations etc. These networks are deployed in an ad-hoc manner with the nodes in the network sharing the same communication medium. Sensor nodes are usually battery operated and are unattended after deployment. Sensor life time depends mainly on the life time of battery. So power saving is a critical issue in Wireless Sensing Networks (WSN). The main functions of a wireless sensor network are sensing; processing; and communication. The sensing circuitry consumes less power than the processor. But the power consumption of the radio communication is much more than that of the processor. Several energy saving schemes have been proposed for the WSN which includes power saving hardware design, power saving topology design, power efficient Medium Access Control (MAC)- protocols, and network layer protocols.

MAC protocols plays a vital role in the energy saving process of a WSN. It is required in the sensor networks to co-ordinate the sensor networks' access to the shared medium. MAC schemes for sensor networks can be fundamentally categorized into contention-based or scheduling-based schemes. The main advantages of contention based schemes in WSN include; no synchronization requirement, no central scheduler required, more robust to the network dynamics, no clustering necessary, more suitable for event-driven WSNs. However, in terms of energy savings, contention-based schemes are not attractive. The resources of wastage of energy in contention-based schemes during communication include collision, overhearing, control packet overhead and idle listening. Scheduling-based schemes attempt to determine the network connectivity first and design collision-fee links to each node. Links may be assigned as time slots (TDMA), frequency bands (Frequency Division Multiple Access (FDMA)), or spread spectrum codes (Code Division Multiple Access (CDMA)). TDMA schemes have a distinct advantage over the other methods in terms of energy conservation [18]. Except for the transmission, receiving and sensing durations, nodes can be put to sleep and highest amount of power savings possible. The main disadvantage of the TDMA scheme is that it requires time synchronization.

II. RELATED WORKS

Presently rural irrigation depends on the natural resources and experience of skilled farmers. There is a frequent electric supply failure and rectification of the same takes weeks together in rural areas which adversely affects the irrigation and farmers may have to adopt for other sources of electricity and it is costly too. Presently there is no efficient and controlled utilization of water or fertilizer.

Sensor-based irrigation systems have been studied for many applications [15],[4][9],[21],[17]. Reference [21] compared indirect estimates with direct measurement of soil moisture. Reference [9] used a control system for apple tree irrigation management using tensiometers. Reference [17] used an automated irrigation control system for management of greenhouse container plants. Shock et al. (1999) used a similar approach but transmitted data from the data loggers to a central data logging site via radio. This system allowed up to 16 Watermark® soil moisture sensors to be wired into apropriertary data logger/transmitting box. But, unless all the sensors were placed in close proximity to the data logger, this system still required extensive cabling. The expense of the data loggers prevents a dense population of sensors in the field. Allen (2000a) evaluated an irrigation management system that can provide continuous real-time or near real-time soilwater content information to the irrigation system operator. This system used two different data loggers to collect and store data from Watermark® soil moisture sensors (Irrometer Co., Riverside, CA, USA). The data loggers were installed in the field in close proximity to the sensor and wired to the sensors. However, this system required the operator to visit the data loggers for data downloading and thus did not provide a wireless solution.

A well-designed irrigation system is an essential requirement for a profitable and environmental friendly irrigation. Software design for automated irrigation control has been studied in reference[1]. They designed and simulated solid-set sprinkler irrigation systems by using a software that allowed to the design of a simplified layout of the irrigation system. However, their software provided limited control due to the lack of feedback in-field sensors. Wireless radio frequency technology has provided opportunities to deploy wireless data communication in agricultural systems [6],[12].

Energy conservation in WSN is very important. Different types of algorithms have been proposed for the sensor networks. C. Srisathapornphat, C.C. Shen has proposed a co-ordinated power conservation(CPC) algorithm to facilitate power conservation for ad hoc networks. CPC uses a set of backbone nodes selected over an ad hoc network to coordinate power conservation. W. Ye, J. Heidemann, D. Estrin has proposed an energy-efficient MAC protocol for WSN – SMAC. The main goal in this MAC protocol design is to reduce energy consumption, while supporting good scalability and collision avoidance. This protocol tries to reduce energy consumption from all the sources that have been identified to cause energy waste, i.e. idle listening, collision, overhearing and control overhead. Although, SMAC saves more power than 802.11, it does not adapt to network traffic very well since it uses a fixed duty cycle for all the sensor nodes. A duty cycle tuned for high traffic loads results in energy wastage when the traffic is low, while duty cycle tuned for low traffic loads results in low throughput under high traffic loads. Another drawback in both SMAC is that, they group the communication during small periods of activity. As a result, the protocols collapse under high traffic loads. Energy conservation can be obtained using data aggregation method. But in data aggregation the data will get altered depending upon the technique [16] and it will be approximated to the nearest value. In case of averaging technique, the header node collects the data and it will just find out the average of all the data that are got from the neighboring nodes and then it will inform the average value to the base station[5]. Energy efficiency in wireless sensor networks using sleep mode TDMA scheduling is proposed in reference [10].This method balances energy-saving and end-to-end delay. This balance is achieved by an appropriate scheduling of the wakeup intervals, to allow data packets to be delayed by only one sleep interval for the end-to-end transmission from the sensors to the gateway. The proposed scheme achieves the reduction of the end-to-end delay caused by the sleep mode operation while at the same time it maximizes the energy savings. The only problem in this scheme is that, there is a wastage of energy when all the nodes are listen to Wake Up messages for the whole Wake Up period.

III. PROPOSED SYSTEM

The automatic irrigation done with the help of highly accurate sensors makes irrigation system a unique product. Man power requirement is very less; this could reduce the manpower requirements for farming which is one of the major factors holding back the farmers. As the number of farmers are decreasing day by day this would help the agricultural area to keep up with the other industries. One of the most important benefits of the product is that a single farmer can manage more than one field. This makes the product truly unique in its kind.

Automatic irrigation is done with the help of two sensors, solenoid valves and a pump. The data given by the sensors are interpreted by microcontroller and it activates the motor according to the need of soil. The main objective of this paper is to provide an energy efficient algorithm for the wireless sensor communication used in an automated irrigation system. The wireless communication can be of two types- single hop or multi hop. In this paper we are using a single hop communication between the source and sink. Data aggregation method is providing better performance so this concept is used to give a better energy efficiency in single-hop communication. In order to provide a good energy conservation a distributed TDMA based scheme which leads to a collision free transmission over the data channel is used. Using this method we can reduce the energy consumption by each node and thereby reducing the overall energy consumption. This method is robust and the failure of single node will affect only the data intended for that node.

A. Direct Communication Method

1) *Basic Scenario*

The basic scenario consists of a base station/sink and twenty sensor nodes is shown in Fig. 1. Each sensor node is equipped with a power amplifier PA2460 and has a range of 1 km. Thus we can cover up to 1acre area of the field using this method. Each sensor node will measure the temperature and the moisture level of the soil. For initializing the network, the base station will assign each node with a unique address. Then each node will switch to the idle state. In the idle state each node will be in receiving mode only. When the base station requires to collect the temperature and moisture level of a particular area, it will broadcast the address of the sensor node which has deployed over there. All the nodes are receiving this

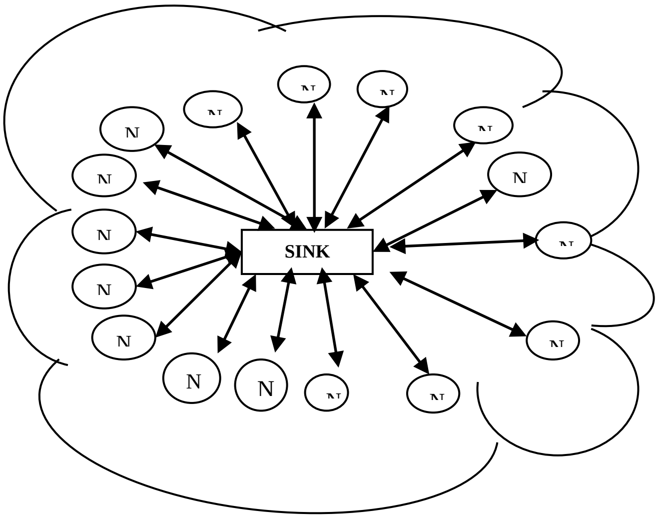

Fig1. Direct Communication method

address but only the addressed node will respond to this request by sending back the present value of the moisture and the temperature of that region. The other nodes will continue in the idle state. After sending the required data the node will go back to the idle state. This process will repeat for all the nodes. Using direct communication method each sensor node sends its data directly to the base station. If the nodes are far from the base station, each node require large amount of transmission power. This will reduce the system life time. So when the nodes are close to the base station this system is efficient.

2) *Sensor Node*

Each node consists of a moisture sensor and the temperature sensor. Fig. 2 shows the block diagram of sensor node. The node's microcontroller program (programmed in C language) corrected and formatted sensor values then output the results to the onboard transceiver. Out of this 20 byte data is used for storing the temperature and 5 bytes are used for the moisture level. The remaining 11 bytes are reserved for the future use. Most of the time the sensor node will be in the receive only mode so that the energy consumption is minimized. The sensing of environment and data transmission will occur whenever it is requested by the base station

Table 1 Format of the data from the sensor node

Temperature data	Moisture data	Unused bytes
4 Byte	5Byte	11 bytes

3) *Soil Moisture Sensor:*

The Soil Moisture sensor is used as a tool to optimize irrigation and to warm of plant stress at the dry or wet ends of the scale. It is a high performance and accurate sensor. The VG400 series soil moisture sensor probes from Vegetronix enable precise low cost monitoring of soil water content. Because the probe measures the dielectric constant of the soil using transmission line techniques, it is insensitive to water salinity, and will not corrode over time as does conductivity based probes. The probes are small, rugged, and consume under a mA of power.

4) Temperature Sensor

LM35 is used as the temperature sensor. Thermistors are temperature sensitive resistors. All resistors vary with temperature, but thermistors are constructed of semiconductor material with a resistivity that is especially sensitive to temperature. However, unlike most other resistive devices, the resistance of a thermistor decreases with increasing temperature. That's due to the properties of the semiconductor material that the thermistor is made from. For some, that may be counterintuitive, but it is correct. Resistance drops is a very small value in a range around room temperature. Not only is the resistance change in the opposite direction from what we expect, but the magnitude of the percentage resistance change is substantial.

5) Base Station

The base station consists of a transceiver, processor, and LCD display. The basic block diagram is shown in the Fig 4. After getting the value of the moisture level and the temperature, the base station will compare this value with the threshold value which is already stored in the database. If the measured value is less than the required value, the controller will do the necessary actions. The same procedure is repeated for all the nodes.

6) Solenoid Valve:

A solenoid valve is an electromechanical valve for use with liquid or gas controlled by running or stopping an electrical current through a solenoid, which is a coil of wire, thus changing the state of the valve. The operation of a solenoid valve is similar to that of a light switch, but typically controls the flow of air or water, whereas a light switch typically controls the flow of electricity. Solenoid valves may have two or more ports: in the case of a two-port valve the flow is switched on or off; in the case of a three-port valve, the outflow is switched between the two outlet ports. Multiple solenoid valves can be placed together on a manifold. Solenoid valves are the most frequently used control elements in fluidics. Their tasks are to shut off, release, dose, distribute or mix fluids. They are found in many application areas. Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of the materials used, low control power and compact design. We are using these valves to control the flow of fertilizers and water to the mixer. Besides the plunger-type actuator which is used most frequently, pivoted-armature actuators and rocker actuators are also used.

7) Pump

The pump is used for the purpose of pumping water in the storage tank to the field. It works according to the instruction of micro controller. So it can pump the water whenever it is needed.

B. Data Aggregation Method

Data aggregation plays a major role in reducing the energy consumption by the sensor nodes and thereby increasing the network life time efficiently. The difference between the data aggregation and data accumulation is that, in data accumulation the header node collects the data from all the nodes and it will just bypass them to the base station without altering the data. But in case of data aggregation the header node collects the data from all the nodes and aggregates them depending on different techniques. Figure 2 and figure 3 shows the basic scenario of the data aggregation. The data being sensed by the nodes in the network must be transmitted to a base station. In this model base station is fixed and located far from the sensors. Data collected from each node is combined together into a small set of information.

Data aggregation is also known as data fusion. Sensor networks contain too much data for an end-user to process. Therefore, automated methods of combining or aggregating the data into a small set of meaningful information are required. For data aggregation nodes are designed in such a way that if the transmitting node fails, it will not affect the network performance and also due to the presence of error bound the header will transmit the data only if the aggregated data is beyond the limit. Nodes organize themselves into clusters with one node acting as the cluster head. In this paper, a sink/ base station acts as the super cluster head. All the sensor nodes are grouped into 3 clusters , each contains six nodes and a cluster head. The communication between sink and cluster heads is based on the TDMA. The communication within each cluster is also based on TDMA method. The basic operation is same as the single – hop method. But here we have two stages of communication.

1) Communication between base station and cluster heads.
2) Communication between cluster heads and the cluster members.

All the nodes in the network are assigned with a unique address and it is known to the base station. Each node acts as the cluster head based on a TDMA schedule. This schedule is broadcast to the nodes in the clusters. Whenever the cluster is formed, based on the schedule all the nodes are transmitting their energy information to the base station. The node which is having the highest energy among all the nodes in a cluster is assigned as the cluster head of that cluster by the base station. Initially all the nodes including the cluster heads will be in the idle state. Whenever the base station needs a data (temperature and moisture value) from a particular area, it will send the address of the cluster head in that area. Now the addressed cluster head will switch from it's idle state to Active state. Now the cluster head will send a request to it's members by sending the address of the member nodes based on the TDMA schedule. i.e. only one node is addressed in particular time slot. Each node send data during their allocated time slot. Now the communication is similar to that in the single – hop method discussed above. The cluster head node must keep it radio ON to receive all the data from the member nodes. When all the data has been received, the cluster head performs the aggregation to compress the data. This data is send to the base station. This process is repeated in all the clusters. After certain time the next round begins with each cluster is assigned with a new cluster head. The new cluster head is selected based on the energy. Using this algorithm we can increase our range of the coverage area and reduce the energy consumption of each sensor nodes.

Basically, data aggregation can be done using four methods. They are based on:

1) Sum
2) Minimum
3) Maximum
4) Averaging

In case of summing technique, the Header node collects the data and it will give the added value to the base station. The major disadvantage in this approach is that the base station will not be able to decide how many nodes exactly gave the data and also it will not be able to find out how many nodes failed during transmission. The summation scheme is represented as follows:

$$\sum_{i=0}^{n} P_i \qquad (1)$$

Where,

i = Node Number

n = Maximum Number of Nodes

P_i = Data present in each node at that instant.

In case of minimum technique, the header node collects the data and it will find out the data with minimum value. Say for example: temperature monitoring, only the minimum degree value that are collected will be informed to the base station. The major disadvantage in this approach is that the node which is far away from the source will always produce minimum value, so it will be very difficult to find the exact temperature distribution in that area. The minimum scheme is represented as follows:

$$\text{Min}(P_0, P_1, P_2, P_3, P_4, P_5)$$

Where,

Min() = Function used to find the minimum In case of maximum technique, the header node collects the data and it will just find out the data with maximum value. Say for example: temperature monitoring, only the maximum value which are collected will be informed to the base station. The major disadvantage in this approach is that the node which is nearer to the source will always produce maximum value, so it will be very difficult to find the exact temperature distribution in that area. The maximum scheme is represented as follows:

$$\text{Max}(P_0, P_1, P_2, P_3, P_4, P_5)$$

Where,

Max() = Function used to find the maximum Value.

In case of averaging technique, the header node collects the data and it will just find out the average of all the data that are got from the neighboring nodes and then it will inform the average value to the base station. The major advantage in this method is that, since the header node performs averaging technique, it will be very useful for the base station to find exactly how many nodes have transmitted their data and also how many nodes failed during transmission. Also in this method because of averaging the exact temperature distribution in the corresponding area can also be found easily, because of these advantages we are following this approach for efficient data aggregation. The averaging scheme is represented as follows:

$$\frac{\sum_{i=0}^{n} P_i}{n} \qquad (2)$$

Where,

i = Node Number

n = Maximum Number of NodesP_i = Data present in each node at that instant.

A) *Methodology*

In case of Fig. 2. (i.e.) without data aggregation the header node collects all the readings from the remaining nodes and it will transmit all the data individually to the base station, as a result energy is consumed a lot in case of normal scenario. It is because in Fig 5, we can see that the header node 0 transmits all the four data that are received from node1, node2, node3, and node4. Since it is communicating to the base station, energy consumption is more in this approach. To prevent this lose of energy we are going for aggregated scenario (i.e.) Fig. 6.

$$\frac{47+51+55+61}{4} = 53.5$$

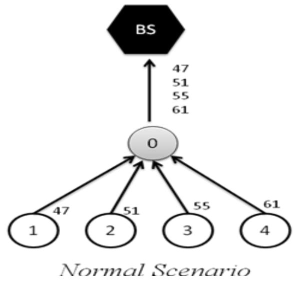

Fig.2 Header without Aggregation

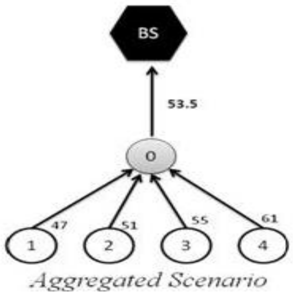

Fig. 3 Header with aggregation

In case of Fig. 3. (i.e.) with data aggregation, the header node collects all the readings from the remaining nodes and it will aggregate them using averaging technique, after averaging the value is found to be 53.5, now the header node will transmit only one data instead of transmitting all the four data. As a result energy is saved a lot in case of aggregated scenario (i.e.) Fig. 3

IV.RESULTS AND ANALYSIS

In this paper two different energy conservation mechanisms have been analyzed based on the TDMA scheduling for the real time application – automatic irrigation systems. Both the methods provide good energy conservation compared to other conventional methods. The single-hop method provides a collision free data transmission. Network simulator-2(NS-2) (www.isi.edu/nsnam/ns/) has used for the analysis of both the algorithms. The matrices used here for the performance analysis are average energy and the throughput of the network. Graphs are plotted for the energy of the network over the time. It shows that, the energy of the network decreases as a function of time. Then the throughput of each node is calculated and plotted. For the simulation purpose the initial energy of each node has been selected as 100 J. From the real time system it is found that the energy needed when the node is in transmission mode is 1 J/s and for receiving mode is 0.5 J/s.

A)Direct Communication Method

The simulation results shows that the amount of energy consumption can be reduced using the single hop method. Fig. 4 shows the relation between energy and time for the network. From graph it is clear that the energy decreases as a function of time. In this method the final energy reaches up to 48 J from the initial energy of 100 J. It shows that energy decreases as time increases.

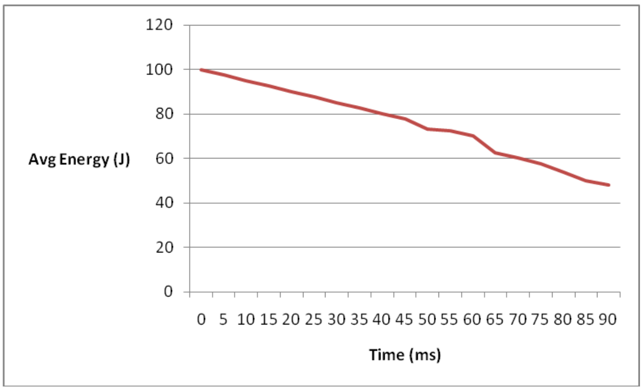

Fig. 4 Energy of the Network for direct communication method

The final energy of each node is found and Fig. 5 shows the graph between the node and final energy of each node. It gives us the value of final energy in each node after the end of simulation. From the graph it is clear that the

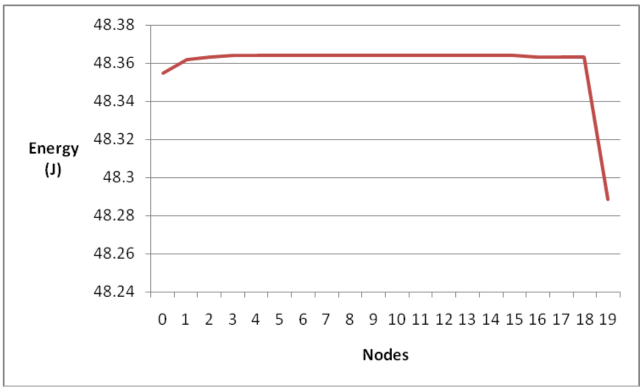

Fig. 5. The final energy of each node

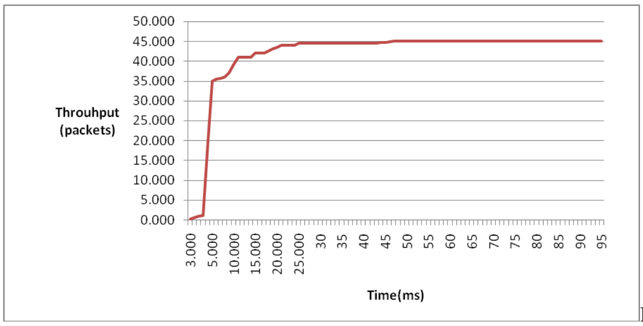

Fig.6 average throughput of the network

node 21 which is the sink node has the minimum energy as it is always taking part in communication. All other nodes are having higher energy than the sink node because they are going back to the idle state after the time slot which is allotted for them. So we could save some amount of energy by switching the nodes back to the idle state while it is not taking part in the communication. Another parameter for performance evaluation is the throughput of the network. It is the number of packets successfully received divided by time. Figure 6 shows the throughput of the network.

B)Aggregation Method

The main objective of the aggregation method is to reduce the energy consumption and to increase the network throughput. The simulation results show that objective could be met by reducing the consumption of energy and by increasing the throughput of the network.Fig. 8 shows the average energy of the network. From the graph it is clear that the average energy has reached the value of 58 J from the initial energy of 100 J. Fig. 9 shows the final energy of each node. Three dips are seen in the graph. They correspond to the final energy of each cluster heads (i.e, node 6,13 & 20. Fig. 2 shows the scenario). The reason is that the active time of the cluster heads are more compared to other member nodes in the networks. But it is seen from the result that even the final energy of cluster head is more

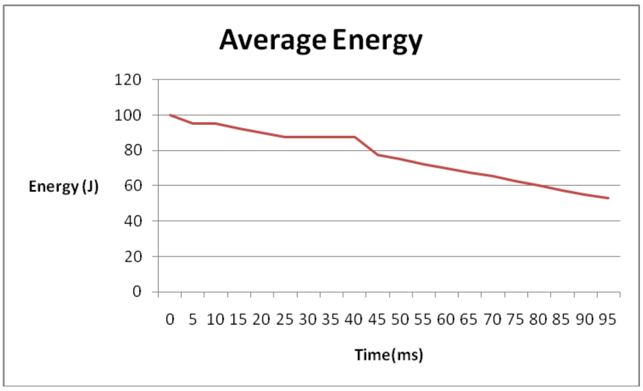

Fig.7 Average energy of the network for data aggregation method

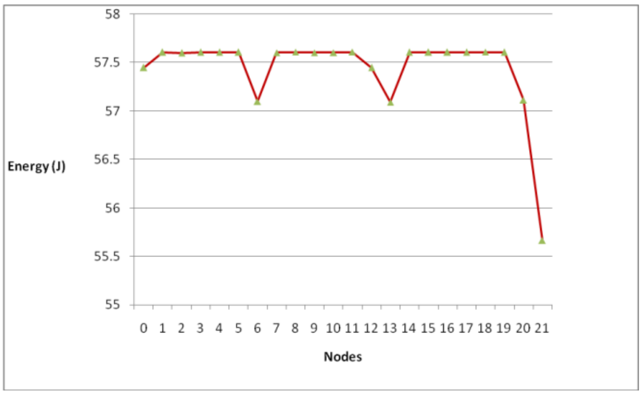

Fig 8. final energy of each node

than the final energy of each node in the direct communication method.

Next the throughput of the network can be seen in the Fig. 9. Graph shows that the throughput of the network also has increased by a considerable value. It has increased from the 45 × 1000 packets to 58 × 1000 packets while we are moving from direct communication method to data aggregation method.

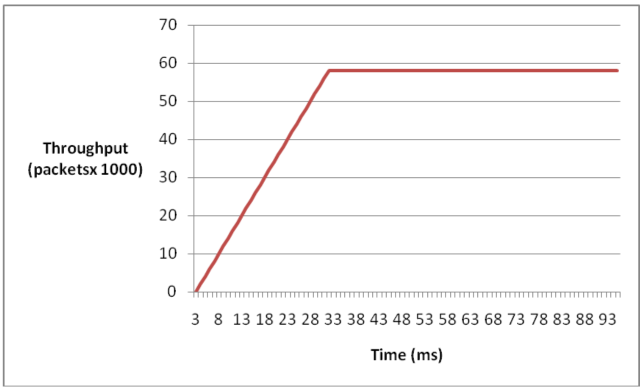

Fig. 9 Average throughput of the network for data aggregation method

V COMPARISON BETWEEN SINGLE – HOP AND DATA AGGREGATION METHOD

In this paper, two methods have proposed for the conservation of the energy in the WSN. Both the methods are working according to the principle of TDMA. From the analysis and the simulation results it is clear that aggregation method is having better performance compared to the single-hop method. The metrics used for the analysis are the average energy of the nodes and the throughput of the network. It is clear from the Fig. 11 that the final energy of the network in the aggregation method is greater than that of the single-hop method. The residual energy has increased around 10 %. For the throughput comparison the throughput of the base station vs time for both the methods have plotted. It is shown in the Fig. 11. From the figure we can understand that, the throughput of the base station in aggregation method is 58 × 1000 packets and for the single – hop method is 45×1000 packets. Thus there is a 13 % of the increase in the throughput.

The energy consumption is a key factor for routing protocols in WSN. So far, many energy conservation algorithms have been proposed for the WSN. In this paper an energy efficient TDMA based algorithm has proposed for an automatic irrigation systems. Two different methods are used based on this TDMA scheduling. The first method uses a direct communication between the sink and the source nodes. Through this method a considerable amount of energy has saved. The second method uses an aggregation method in which the sink/base station collects the data from different cluster heads. Using this method the energy conservation obtained is more than that obtained from the direct communication method. For better performance, cluster heads are selected based on the energy of the nodes in the cluster after the completion of each cycle of

TDMA.

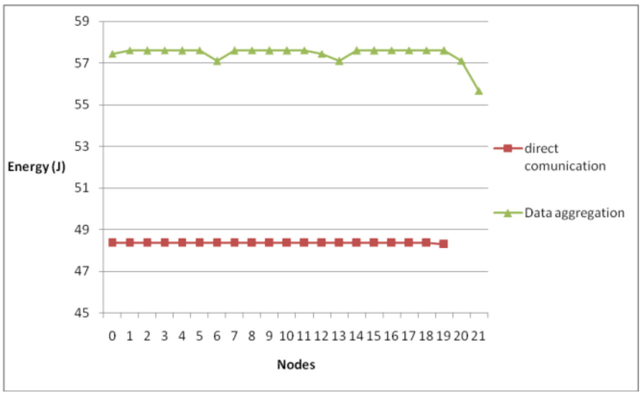

Fig. 10. comparison of final node energy

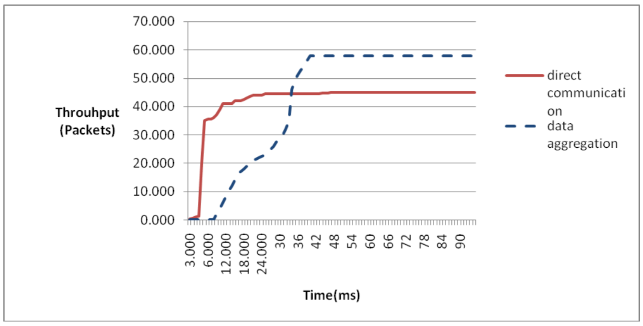

Fig.11 comparison of throughput

VI CONCLUSION

In this paper two different energy conservation mechanisms have been analyzed based on the TDMA scheduling for the real time application – automatic irrigation systems. Both the methods are providing good energy conservation compared to other conventional methods. The direct communication method is providing a collision free data transmission. From the simulation results it is found that the aggregation method is showing better performance than the direct communication method in terms of average energy and the throughput of the network. As a future work the energy conservation using different schedules can be done and those methods can be compared with the proposed methods.

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