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Comparative Analysis of TDMA Scheduling Algorithms in Wireless Sensor Networks

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***Abstract*– Energy conservation is a major issue in Wireless Sensor Network (WSN). In order to obtain energy conservation, Time Division Multiple Access (TDMA) has been discussed as one of the potential solution. Many researchers proposed TDMA as a Media Access Control (MAC) in order to conserve energy. The main advantage to using TDMA MAC is avoidance of collision of data packets during transmission and the added facility to use sleep modes. The use of sleep mode enables switching off the radio antennas thus reducing the energy conservation. Prior to usage of TDMA MAC, scheduling of the sensor nodes, i.e. providing time slot to the sensor nodes must be performed. Efficient scheduling of transmitting time slot in a TDMA is important for low power WSN. In this work, two decentralized scheduling algorithms Distributed Randomized TDMA (DRAND) and Deterministic Distributed TDMA (DDTDMA) are compared. In these algorithms, flowing the messages among the sensor nodes the scheduling is performed by assigning transmitting time slot to each node. So, their efficiency is analyzed based on schedule length, message complexity and convergence time to obtain scheduling. It was found that DDTDMA is an efficient algorithm than DRAND in terms of schedule length, message complexity and convergence time.**

***Keywords*– Wireless Sensor Network, Time Division Multiple Access, Distributed Randomized TDMA and Deterministic Distributed TDMA**

I. INTRODUCTION

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location [1]. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting [3]. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. Wireless sensor networks have a wide range of potential applications including environment monitoring, military scenarios and robotic exploration. Many of the sensor networks will be battery-powered, so lifetime is the most essential requirement. This motivates the proposal of many MAC protocols [2].

In order to conserve energy, TDMA MAC has been proposed by many researchers. The main advantage to using TDMA MAC would be avoidance of collision of data packets during transmission and the added facility to use sleep modes. The use of sleep mode will enable switching of the radio antennas thus reducing the energy conservation. It should be noted that the major consumption of energy takes place during transmitting and receiving data packets in wireless devices. In TDMA protocols, a TDMA frame is divided into time slots and each admitted node is assigned one. The transmission schedule allows nodes to send and receive without collision [5].

The main objective of scheduling is to avoid one-hop and two-hop collision. In one-hop transmission it is not possible to transmit message from one node (say node A) to another node(say node B) while another node (B) is transmitting data to the node (A) itself, otherwise there may be collision in transmission of data i.e. One-hop conflict. Similarly in two hop transmission it is not possible to transmit message from two- hop node (C) to one hop node (B) while transmitting node (A) is transmitting data to one-hop node (B), otherwise there may be collision in transmission of data i.e., Two-hop conflict. The constraints of collision in the wireless communication process:

1) Any node can't simultaneously send or receive data, nor send and receive data.

2) The existence of hidden terminal problem causes the interference of channel, leads to transmission collision [4].

So to avoid collision in one-hop and two-hop, TDMA MAC can be used.

Efficient scheduling of time slots in a time division multiple access scheme (TDMA) is important for low power wireless sensor networks. Existing algorithms are either centralized with poor scalability, or distributed but with high complexity. This work comprises of study of two decentralized TDMA scheduling algorithms i.e., DDTDMA and DRAND and proposes which algorithm is better in terms of schedule length, running time and message complexity.

II. METHODOLOGY

The performance analysis comparison of the two distributed TDMA scheduling algorithms: DRAND and DDTDMA were performed in this work. The comparison between two scheduling algorithms was done in terms of schedule length, message complexity and running time.

A) Flowchart for DDTDMA

Notations:
i=node
I slot=time slot of node i
T=time frame

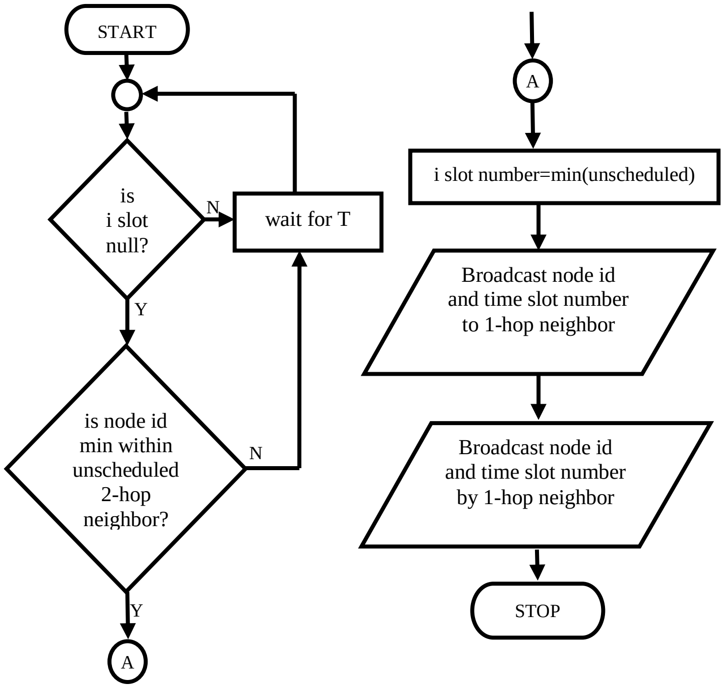

Figure 1: Flow chart of DDTDMA

The basic idea of DDTDMA is to let each node decide its own slot according to the information gathered from neighbour nodes and packet collisions are gracefully avoided during scheduling. Particularly, neighbourhood information refers to whether a node's two-hop neighbours are scheduled. As a deterministic collision-free algorithm is used in scheduling, there is no need to wait for an acknowledgement from neighbours to avoid possible collision. The scheduled node broadcasts its slot assignment to one-hop neighbours. Then those one-hop neighbours broadcast this information to update two-hop neighbours. These two processes are called one-hop broadcast and two-hop broadcast [6]. These are repeated in every frame until finally all nodes are scheduled.

B) Flowchart for DRAND

Notations:
T=time frame
t=idle time
j=node
C_j =contending nodes
P=probability
P_j=Node probability
P_i= other node probability

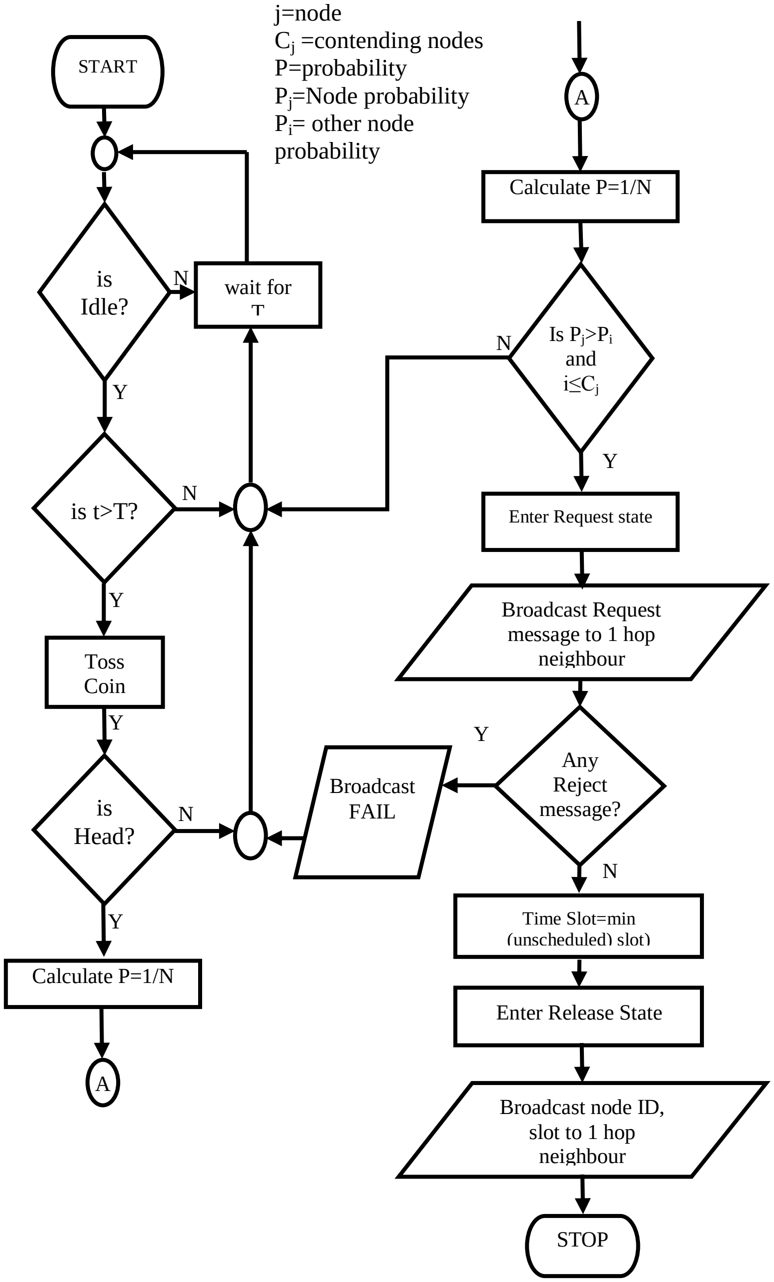

Figure 2: Flow chart of DRAND

Each node first runs a neighbour discovery protocol to get its neighbourhood information. Then the DRAND algorithm was executed and a TDMA time slot was assigned to each node [7]. Finally nodes disseminate their slot information to their two-hop neighbourhood so that data transmission may start using this slot information.

III. SIMULATION AND RESULTS

A) Workflow Diagram

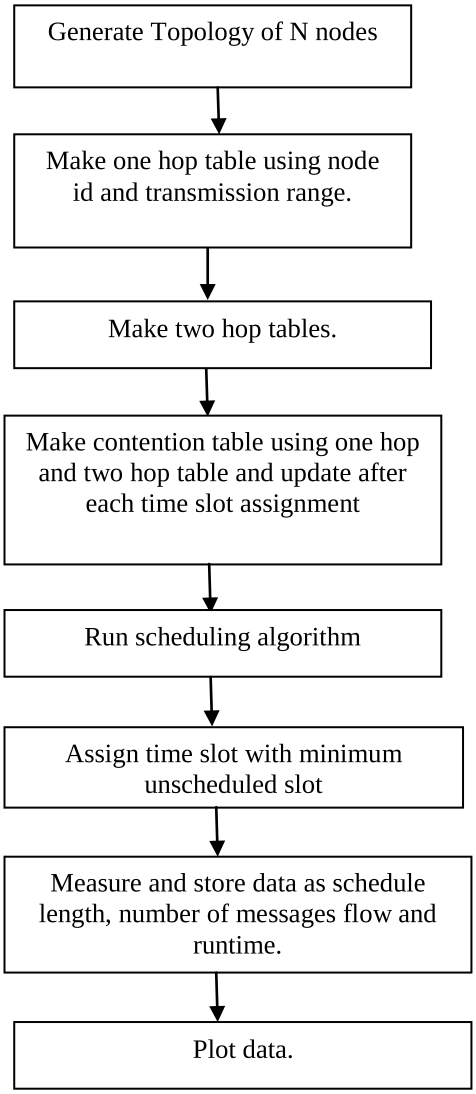

Figure 3: Work Flow Diagram

B) Simulation Setup

- The network topology is generated by randomly deploying N nodes into the area of √N*√N units, so that when N varies the node density within transmission range is kept as constant.
- In order to represent different node density, transmission range from 1 to 2 units has been varied and 100 numbers of nodes is fixed in a 10X10 area.
- The initial frame length is set to 100 slots per frame.
- To avoid the impact caused by network topology, each configuration in the experiment is simulated by 20 different deployments of topology and the average results of schedule length, message complexity and running time are computed.
- For each configuration the plots of simulation results are shown in normalized units.
- Standard deviation of the 20 measured data is also computed in order to analyze the data pattern.
- Standard deviation of the 20 measured data for single network topology is also computed in order to analyze the data pattern and justify the approach of the algorithms.
- Performance of DRAND and DDTDMA is evaluated in three aspects: schedule length, message complexity and running time.
- Scalability of DRAND and DDTDMA is examined by varying the range of nodes from 100 to 500 in the difference of 50 nodes in each range keeping transmission range fixed to 1 unit.

C) Results

Figure 4 shows the comparison of schedule length between DRAND and DDTDMA. The simulation result shows that DDTDMA and DRAND achieve nearly the same schedule length. However, DDTDMA have lower schedule length than DRAND.

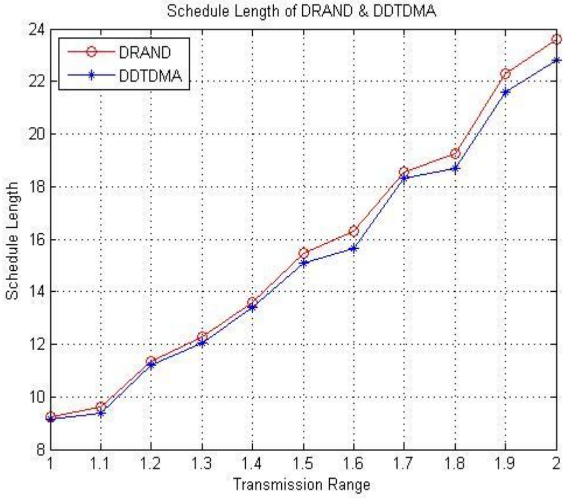

Figure 4: Comparison of schedule length between DRAND and DDTDMA

Figure 5 shows comparison of message complexity between DRAND and DDTDMA. Simulation result shows that DDTDMA outperforms DRAND in message complexity. The message complexity of DDTDMA is around 50% of DRAND.

Figure 6 shows comparison of convergence time between DRAND and DDTDMA. Simulation result shows that DDTDMA outperforms DRAND in convergence time. The convergence time of DDTDMA is around 40% of DRAND.

Standard deviation of twenty measured data in each transmission range is plotted for Schedule Length of DRAND and DDTDMA. Figure 7 shows that nature of deviation is almost same for both algorithms but it is seen that deviation is lower in DDTDMA than DRAND.

Standard deviation of twenty measured data in each transmission range is plotted for Message Complexity of DRAND and DDTDMA. Figure 8 shows that nature of deviation is almost same for both algorithms but it is seen that deviation is lower in DDTDMA than DRAND.

Standard deviation of twenty measured data in each transmission range is plotted for Convergence Time of DRAND and DDTDMA. Figure 9 shows that deviation is lower in DDTDMA than DRAND.

Standard deviation of twenty measured data in each transmission range is plotted for Schedule Length of DRAND and DDTDMA on single network topology. Figure 10 shows that deviation is seen for DRAND where as deviation is zero for DDTDMA.

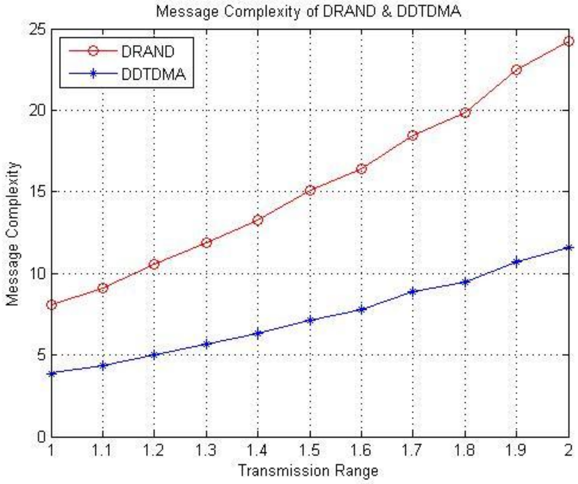

Figure 5: Comparison of message complexity between DRAND and DDTDMA

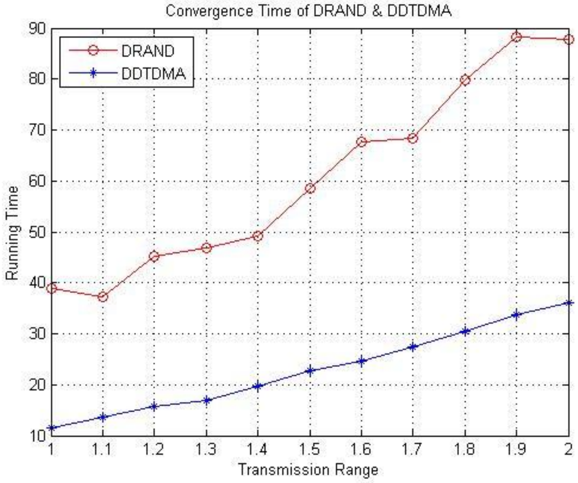

Figure 6: Comparison of convergence time between DRAND and DDTDMA

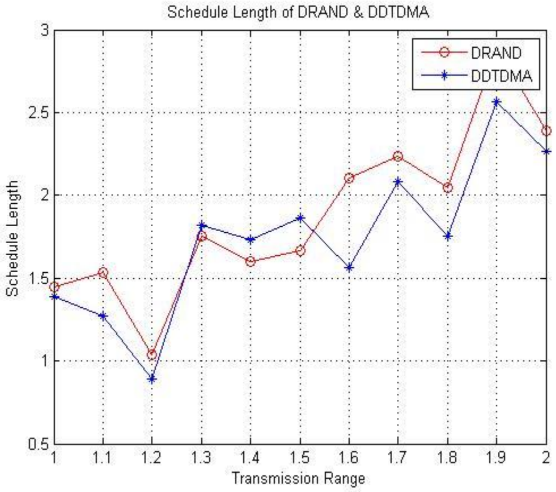

Figure 7: Comparison Result of Standard Deviation of Schedule Length for DRAND and DDTDMA

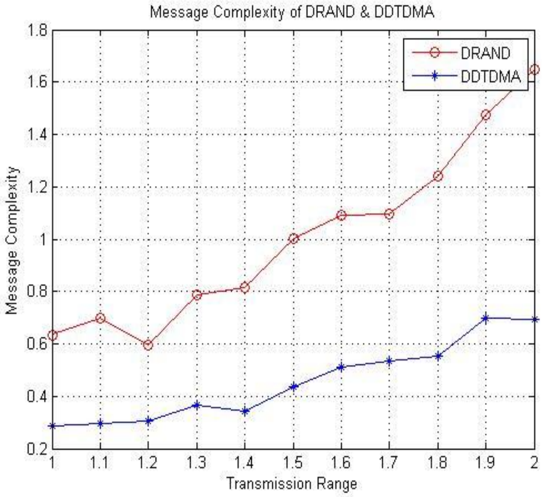

Figure 8: Comparison Result of Standard Deviation of Message Complexity for DRAND and DDTDMA

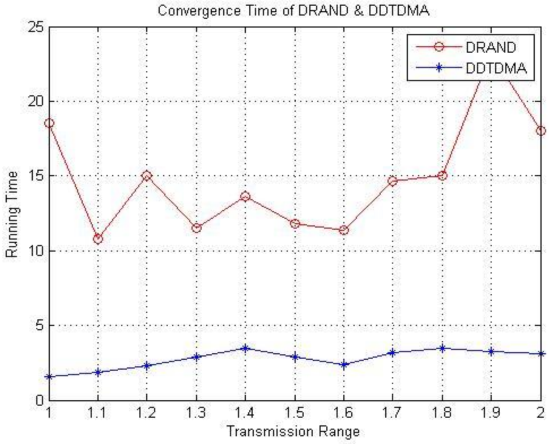

Figure 9: Comparison Result of Standard Deviation of Convergence Time for DRAND and DDTDMA

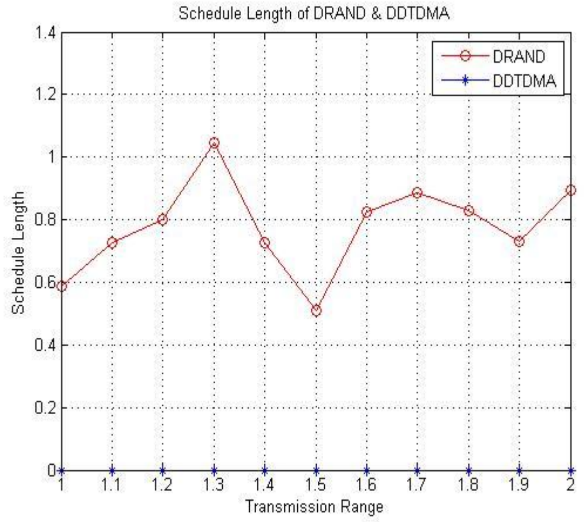

Figure 10: Comparison Result of Standard Deviation of Schedule Length for DRAND and DDTDMA on single Network Topology

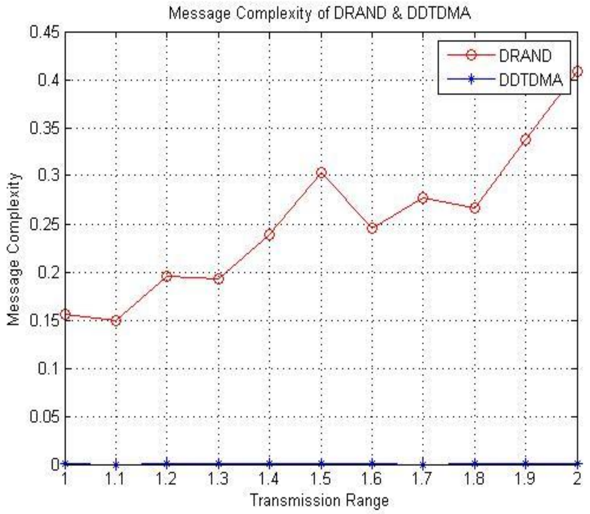

Figure 11: Comparison Result of Standard Deviation of Message Complexity for DRAND and DDTDMA on single Network

Standard deviation of twenty measured data in each transmission range is plotted for Message Complexity of DRAND and DDTDMA on single network topology. Figure 11 shows that deviation is seen and increased as the transmission range is increased for DRAND where as deviation is zero for DDTDMA.

Standard deviation of twenty measured data in each transmission range is plotted for Convergence Time of DRAND and DDTDMA on single network topology. Figure 12 shows that deviation is seen and abruptly changing as the transmission range is increased for DRAND where as deviation is zero for DDTDMA.

Figure 13 shows that the scheduled length is nearly the same in DRAND and DDTDMA as the number of nodes increased. However, DDTDMA have lower schedule length than DRAND.

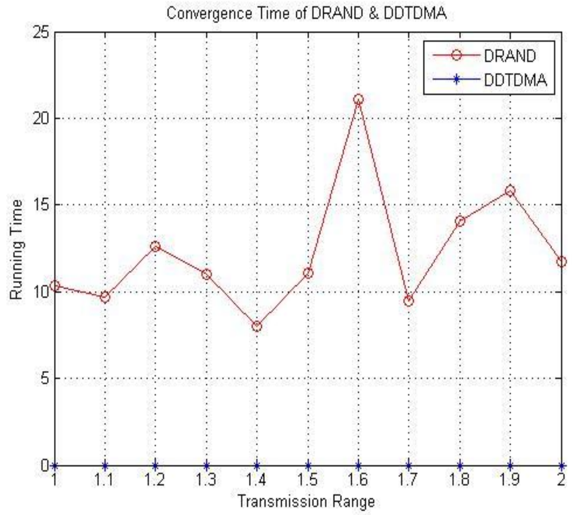

Figure 12: Comparison Result of Standard Deviation of Convergence Time for DRAND and DDTDMA on single Network Topology

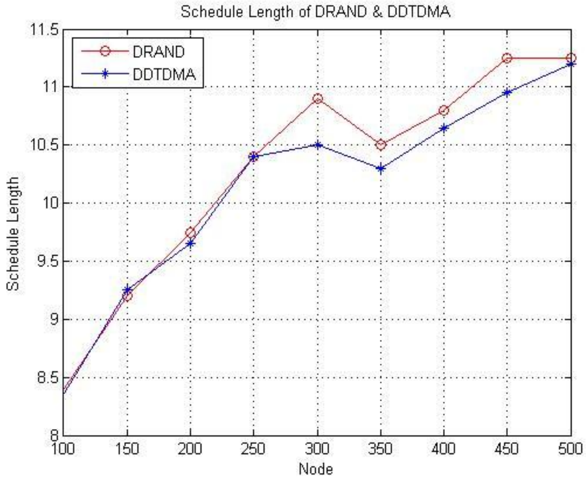

Figure 13: Comparison Result of Scheduled Length for DRAND and DDTDMA on increased number of Nodes

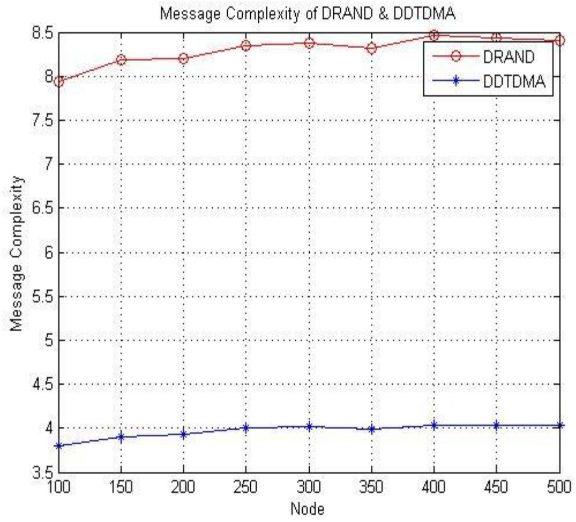

Figure 14: Comparison Result of Message Complexity for DRAND and DDTDMA on increased number of Nodes

Figure 14 shows that the message complexity is very low in DDTDMA than DRAND as the number of nodes increased. The message complexity of DDTDMA is around 47% of DRAND.

Figure 15 shows that the convergence time is very low in DDTDMA than DRAND as the number of nodes increased. The convergence time of DDTDMA is around 30% of DRAND.

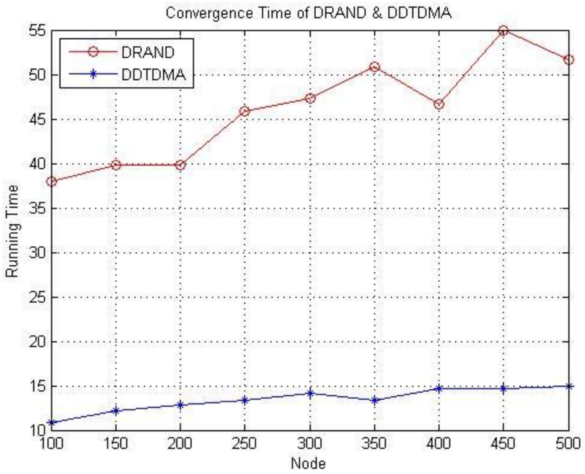

Figure 15: Comparison Result of Convergence Time for DRAND and DDTDMA on increased number of Nodes

The scalability of DRAND and DDTDMA is examined by ranging nodes from 100 to 500. The transmission range is fixed to 1 unit. The simulation results in Table 1 and Table 2 shows that the performance of the DDTDMA algorithm remains stable as the number of nodes increases which means DDTDMA is suitable for high density sensor networks.

Table 1: Scalability of DRAND

No. of Nodes	Running Time	Message Complexity	Schedule Length
100	37.95	7.9315	8.40
150	39.85	8.1910	9.20
200	39.75	8.1970	9.75
250	45.85	8.3426	10.40
300	47.30	8.3685	10.90
350	50.80	8.3179	10.50
400	46.65	8.4649	10.80
450	54.95	8.4339	11.25
500	51.65	8.4059	11.25

Table 2: Scalability of DDTDMA

No. of Nodes	Running Time	Message Complexity	Schedule Length
100	10.80	3.7930	8.35
150	12.20	3.9040	9.25
200	12.80	3.9240	9.65
250	13.30	4.0088	10.40
300	14.15	4.0173	10.50
350	13.30	3.9920	10.30
400	14.65	4.0375	10.65
450	14.65	4.0329	10.95
500	14.9	4.0302	11.20

IV. CONCLUSION

In this paper two decentralized TDMA scheduling algorithms for wireless sensor networks, DRAND and DDTDMA are compared in terms of schedule length, message complexity and running time. Comparing these two scheduling algorithms it was found that DDTDMA efficiently allocates time slots to avoid collisions. Simulation results showed that DDTDMA achieves better performance than DRAND in terms of schedule length, message complexity and running time and so DDTDMA can be applied in wireless sensor networks with large number of nodes.

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