

TDMA-based Real-time Delay Routing with Emergency Data in IWSN

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Abstract: Industrial Wireless Sensor Networks (IWSN) is an emerging technology in the field of industrial automation and control, which is used widely in environment monitoring, data collection and operation control, etc. This thesis proposes a TDMA-based real-time delay routing, with emergency data, for IWSN. Two-hop neighbor information is used from the two-hop velocity-based routing. TDMA is adopted to guarantee a deterministic timing restriction for a real-time requirement. The proposed protocol also considers the link quality to guarantee the reliability of transmission. The proposed protocol is simulated on the OPNET Modeler, and the evaluation results show a low end-to-end delay and a high reliable delivery. In addition, a significantly better performance is shown for emergency data as compared to that for regular data. *Copyright © 2013 IFSA.*

Keywords: IWSN, Routing algorithm, TDMA, Emergency data.

1. Introduction

Industrial Wireless Sensor Networks is an emerging technology in the field of industrial automation and control, which is widely used in environment monitoring, data collection and operation control etc [1]. Recently, several research aspects of interest to researchers concerning IWSN have arisen. The routing algorithm plays an important role and this has involved new challenges in the field of IWSN. Because of the energy and delay requirements of routing protocols in IWSN, it is vital to maintain reliable routes and ensure real-time multi-hop communication in the network [2]. Although the routing protocols have been researched from many different aspects, various problems and challenges while considering real-time, reliable delivery in a harsh industrial environment still exist. The majority of the routing protocols in IWSN are based on Carrier Sense Multiple Access with Collision Avoidance

(CSMA/CA), but CSMA/CA cannot provide a guaranteed access to the wireless channel as the network dense increases and is very difficult to guarantee real-time delivery in industrial applications because of resource competition [3, 4]. Thus, in this research, the proposed algorithm is based on Time Division Multiple Access (TDMA), which can provide a more deterministic timing restriction for real-time communication in industrial applications, as compared to CSMA/CA. The solution to deal with the new requirements such as real-time, reliable delivery in IWSN is necessary to achieve the quality of service (QoS) in such time-critical industrial wireless sensor networks [5]. Additionally, considering the security of an industrial environment, it is also necessary to take emergency data into account. Thus, in the proposed protocol, a specific queue model will be adopted to handle the priority of the packets.

2. Related Work

Currently, there are many studies proposed in the field of IWSN [6]-[9]. The majority of them are mainly focused on the new requirements of IWSN: real-time, energy consumption, end-to-end delay etc. Some researches consider many aspects such as delay, energy, reliability etc. Although they achieved most of new requirements for WSN, it is difficult to find the trade-off between these requirements.

RTLD [6] is a real-time routing protocol with load distribution in wireless sensor networks. It achieved real-time communication, low energy consumption and a high delivery ratio. However, it only calculated the forwarding metric of one-hop neighbors, which will generate some limitations in relation to choosing the optimal forwarder.

Yanjun Li, Ye-Qiong Song [7] proposed a two-hop neighborhood information-based routing protocol, which provides a real-time delivery in Wireless Sensor Networks. However, in this routing protocol the velocity is calculated by means of geographic information and it is unable to optimize the number of hops which have a significant influence on the delay and energy expenditure [8].

Pham Tran Anh Quang and Dong-Sung Kim [8] determined a gradient routing protocol with two-hop information, which enhances real-time performance with energy efficiency. Although it shows a good performance in relation to the routing protocol, it does not give prior consideration to the emergency packet.

The aim of the proposed routing protocol is to achieve the real-time delivery and high reliability communication when considering an emergency packet. For the MAC layer, it will adopt TDMA instead of CSMA/CA. The advantage of using TDMA is to meet the strict timing requirements associated with industrial applications. It must also consider how to allocate the time slots to the sensor nodes of the network. Another important issue in the proposed protocol involves the emergency packets. The reason for taking emergency packets into account is that transmitting an emergency packet as soon as possible to the sink node is of vital importance in some applications of WSN, such as the monitoring of earthquakes or forest wildfires. In the proposed routing protocol, emergency packets can be delivered in real-time by using priority levels in order to choose the high priority packets to be transmitted first. Thus, the proposed routing protocol will enhance the real-time delivery based on the new industrial requirements of WSN.

3. Network Model

In the proposed routing protocol, the environment is a small size and sparse wireless sensor network that works in a proactive mode where the sensor nodes randomly send the packet to the sink node. In

this wireless sensor network, there is only one sink node and all of the sensor nodes are stationary.

Therefore, because of the fixed network, the neighbor information is unchanged and does not require updating. In this project, the assumption is that every node knows its own location and that of the sink node. The location information can be obtained by GPS technology or the localization protocols for calculating the position of node [10, 11].

This project is implemented in the network layer and is based on TDMA. In TDMA, the frame consists of several timeslots that are allocated to nodes for sending the data from the source to the sink. Currently, there are many researches being conducted into TDMA scheduling in a wireless sensor network and this can be divided into two categories. One is to allocate the timeslot based on the routing information, which can achieve minimum latency [12] while the other is attempting to allocate the timeslot in a reasonable way but without the routing information. In this project, the main focus is on the routing protocol in order to determine the solution for real-time communication in IWSN and the utilization of TDMA is only an important factor which has an effect on this. Thus, the second method is adopted and an attempt is made to realize an adaptive TDMA scheduling method for this specific requirement.

4. Proposed Routing Protocol

In the section, the proposed routing protocol will be presented. The proposed routing protocol is a kind of proactive routing protocol that looks ahead for two-hop neighbor information. It is based on TDMA to guarantee the deterministic delay for the whole wireless sensor network.

4.1. Neighbor Discovery

Neighbor Discovery is the fundamental element of the routing protocol and in many existing routing protocols it is described by a number of different methods. In the proposed routing protocol, basically it uses beacon messages to construct the neighbor information table. With the specific TDMA MAC mechanism, it is also extended to consider the topology of the whole network and the link quality to simplify TDMA frame length.

In the proposed routing protocol, neighbor nodes are not all nodes located in the range of transmission distance. We adopt the specific scheme which is proposed in EARQ [13]. This scheme is kind of directional selection that it only chooses the node in the direction of the sink node. This scheme considers noise and obstacle interference and this solves the problem that the packet may be not received because of obstacles. Although it is directional, it can guarantee the node in the neighbor table can be reached or relay the packet to the corresponding

destination. In order to get two-hop neighbor information, the proposed routing protocol uses two rounds of Hello messages. This scheme is proposed in THVR [7].

Topology control is adopted in the proposed protocol to simplify sensor network and optimize the number of timeslots for TDMA scheduling. The main factor to be considered for topology control is the link quality. In the proposed routing protocol, the sensor network is fixed. To simplify this processing, after creating the original neighbor table, each link between neighbor nodes will be estimated in order to obtain the link quality by using the existing algorithm: Link Quality Assured Topology Control Algorithm (LQATC) [14].

4.2. TDMA Scheduling Initialization

The proposed routing protocol aims to provide real-time communication, so the timeslot allocation in TDMA is key factor mainly determining the end-to-end delay. In the proposed routing protocol, the method of first allocating and then adjusting is the one which has been adopted.

In the phase of Neighbor Discovery, the network is simplified by means of topology control and the two-hop neighbor information is obtained for each node. Based on this information, TDMA allocation starts in the node furthest from the sink node. In each time slot, only one transmitter can send the packet but there is no limitation with regards to the number of receivers. At the beginning of the TDMA allocation, sufficient timeslots will be given for one frame and it allocates one timeslot for each node. Additionally, in order to solve the problem of timeslot collision, a shared timeslot is introduced to the TDMA allocation. Thus the structure of the TDMA frames in this work is divided into two parts: allocated timeslot and shared timeslot. The allocated timeslots are determined in advance for each node and the shared timeslots are reserved for the node requiring more timeslots. At first, the TDMA frame is not fixed and it thus required several times to experiment in order to obtain the empirical value. This is the processing of adjustment and it will be described at a later stage.

Fig. 1 shows an example of the TDMA frame structure. It has six timeslots for the allocated timeslots and four timeslots for the shared timeslots. In the allocated timeslots, the number of receivers is not fixed and it depends on the number of neighbors of the node. From the figure, it can be seen that nodes A and D have two neighbors and the others only have one.

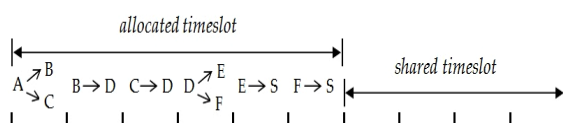


Fig. 1. An example of the structure of a TDMA frame.

As discussed previously, TDMA scheduling of the proposed routing protocol must be adjusted in several experimental feedbacks. At first, all of the shared timeslots are not occupied and are merely reserved for later utilization. When the node encounters a timeslot collision, it will go to the shared timeslot to choose the available timeslot. When the node receives the available timeslot resource from the shared timeslot, then this should change to the allocated timeslot. After testing and experimenting several times, the number of timeslots and shared timeslots in one frame is determined, based on the effects of the experiment. After the processing of the TDMA adjustment, the TDMA timeslot allocation is fixed and will be used periodically in the network.

4.3. Forwarder Selection

In this section, it will present the forwarder selection method. There are three main parts: Gradient-based network setup, Priority model and Forwarding metrics.

4.3.1. Gradient-based Network Setup

Gradient-based networks will be built in the proposed routing protocol, and it uses the scheme proposed in IETF ROLL [15]. The Gradient scheme mainly consists of three steps.

1) Gradient setup: This setup method is typically used in the Gradient Based Routing (GBR) [16], which builds up a hop-count-based gradient during a setup phase [17].

2) Height calculation: The height of the sink node is always set to 0. Other nodes will set their heights equal to the smallest number of hops to the sink node [18].

3) Forwarding techniques: The node sends the packet to its available neighbor with the smallest height, so it can increase the reliability of delivering with the best available node.

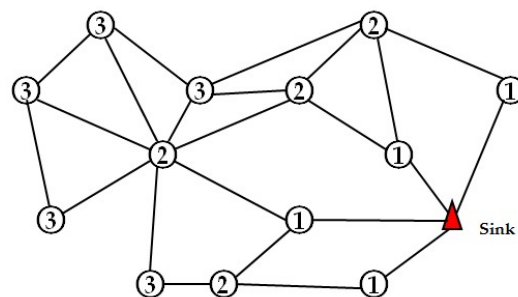


Fig. 2. An example of Gradient-based network.

Fig. 2 shows an example of a Gradient-based network. The red triangle is the sink node and its

height is set to 0. Other nodes set their heights as the smallest number of hops to the sink node.

4.3.2. Priority Model

The proposed protocol classifies the packet as two types of priority: normal packets and priority packets. The queue model adopts the scheme that emergency data is the priority. The priority packet is always inserted into the head of the queue and it can be transmitted when the node obtains the opportunity. It maintains the following rules:

- 1) If there are other priority packets waiting in the queue, the new priority packet is inserted at the tail of these existing priority packets.
- 2) The normal packet is always inserted into the tail of the queue without considering the sequence.
- 3) If the queue is full, the queue will discard the oldest packet to provide a place for the newly coming packet.

Fig. 3 shows the Queuing model in this protocol. In the packet format of sensor data, the emergency data is marked in the field of priority. If this data is priority data it will be inserted into the head of the queue, otherwise it is inserted into the tail of the queue.

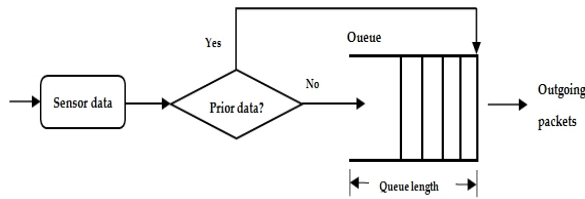


Fig. 3. Queuing model.

4.3.3. Forwarding Metrics

In the section, we will introduce the forwarding metrics using in the proposed algorithm and the main equation is adopted by THVRG [7].

The set of one-hop neighbors of node i , $F(i)$, is defined as being composed of the neighbor of node i in the one-hop neighbor area. The set of two-hop neighbors of nodes i , $F_2(i)$, consists of the one-hop neighbor nodes of $F(i)$, namely the two-hop neighbors of node i . There are two required deadline deliveries defined as t_{set0} , t_{set1} respectively, and t_{set0} is the required deadline delivery of the normal packet and t_{set1} is that of the priority packet. In addition, the corresponding threshold velocities to guarantee the end-to-end delay are defined by

$$S_{th0} = \frac{H_s}{t_{set0}} \quad (1)$$

$$S_{th1} = \frac{H_s}{t_{set1}}, \quad (2)$$

where H_s is the height of the source.

Two-hop velocity is related to the delay of a two-hop neighbor while considering the number of hops instead of the distance between the two-hop nodes. It is calculated by

$$V_i^j = \frac{2}{T(i,j) + T(j,k)}, \quad (3)$$

where $T(i,j)$ is the delay from node i to node j , $j \in F(i)$, and $T(j,k)$ is the delay from node j to node k , $k \in F_2(i)$.

If node j satisfies $V_i^j \geq S_{th0}$, it is included into the set P_0 , namely the potential forwarder set of the normal packet.

If node j satisfies $V_i^j \geq S_{th1}$, it is included into the set P_1 , namely the potential forwarder set of the priority packet.

It is assumed that a packet is received by the forwarding node a at the timeslot n_a , and after running the proposed protocol, it will relay to node b at the timeslot n_b . The per-hop delay is calculated by

$t_{hop} = \tau + \tau \cdot [(n_b - n_a) \bmod M] + t_{queue}$ (5) In (5), τ is the duration of one timeslot, M is the total number of the timeslots in one frame and t_{queue} is the time waiting in the queue [17]. From this equation, the delay of per-hop is determined by the transmission delay, timeslot offset delay and queuing delay.

The node determines whether it relays the packets based on the forwarding probability of node i that is calculated by

$$u_i = \begin{cases} 1 - K_1 \frac{\sum_{j=1}^N e_j}{N} \frac{H_i}{H_s} > \frac{1}{2} \\ 1 - K_2 \frac{\sum_{j=1}^N e_j}{N} \frac{H_i}{H_s} \leq \frac{1}{2} \end{cases}, \quad (6)$$

where $j \in F(i)$, N is the cardinality of $F(i)$, e_j is the packet loss ratio of node j , H_i is the height of node i , H_s is the height of the source node, and K_1 and K_2 are the positive coefficients.

In (6), e_j can be achieved by the link quality as discussed previously, K_1 and K_2 are the value of a function of $(H_i)/(H_s)$ and this is given by

$$K(\beta) = \begin{cases} K_1, \beta > \frac{1}{2} \\ K_2, \beta \leq \frac{1}{2} \end{cases} \quad (7)$$

where $\beta = (H_i)/(H_s)$ [7].

Fig. 4 shows the flowchart of the processing of the forwarder selection. When the node receives the packet or has its own packet to send, after judging whether or not it is priority packet, it will find the potential forwarder in the corresponding set. However, if the potential forwarder set is empty, it must start the initialization scheme to calculate the forwarding information. If in the forwarding set, it can find the potential nodes, it then chooses the node with the best two-hop velocity to calculate the forwarding probability of the node and if the

probability is high, this node will send it; otherwise, it will find another node with the second best two-hop velocity. In this processing, the priority packet will always have priority relation to being handled by the forwarder selection scheme.

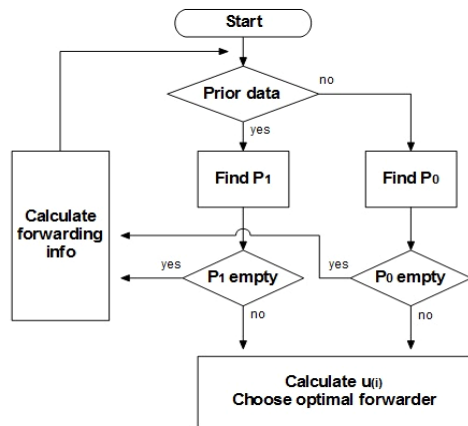


Fig. 4. Flowchart of the processing of forwarder selection.

As Fig. 5 shows, the process model consists of several FSMs. The first three states are part of the

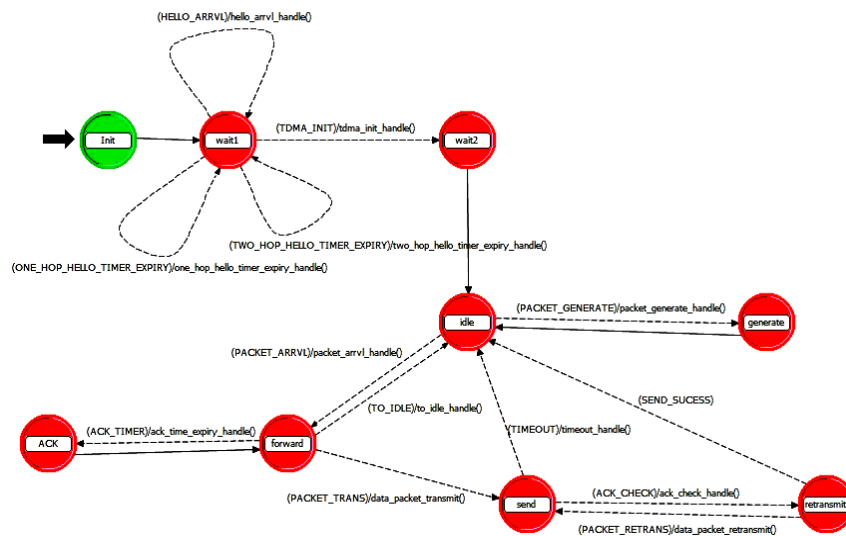


Fig. 5. Process model of the proposed protocol.

5. Evaluations

The proposed protocol is verified by OPNET modeler 17.5. This is a high-level event-based network level simulation tool that operates at packet-level [18]. This paper compares with THVRG. It will analyze the proposed protocol in two aspects: average end-to-end delay and delivery success ratio.

5.1. Simulation Model

In the wireless Medium Access Control (MAC) and physical layer, the IEEE 802.15.4 standard is

adopted. The data rate is 1024 b/s, the bandwidth is 2000 kHz, and the min frequency is 2401 MHz. The modulation is BPSK and in the transmitter, the power is set to 0.01. In this simulation, we have two scenarios that the number of nodes is fixed to 10 and 20 respectively, which are deployed randomly in a 100 m × 100 m area. The transmission range is 60m and the packet length is 32 bit (4 bytes). In order to get the duration of one timeslot, we test the relationship with delay, packet length and distance. The delay mostly depends on the packet length and is 0.03125 s. In this work, the duration of one timeslot in TDMA frame is set to 0.032 s which is a little bit larger than 0.03125.

5.1.1. End-to-end delay and Delivery Success Ratio in Different Traffic Loads

The proposed algorithm is evaluated under different traffic loads while the number of sources is varied from 1 to 6. The packet generate frequency of the source is 1 packet per second.

Fig. 6 shows the minimum, average and maximum end-to-end delay with different traffic loads. It can be seen from the figure, it has an increasing trend for minimum, average and maximum end-to-end delay for multiple sources. This is a consequence of the increased traffic loads and the fact that every source has the same frequency of generating packets. The conclusion that can thus be drawn is that the increasing numbers of sources results in a higher packet generate frequency. Hence it can be determined that a higher traffic load will be the result of a higher frequency. The figure shows that in the heaviest traffic environment, the minimum end-to-end delay stays within 0.5 s and the maximum end-to-end delay is within 1.2 s. It is clearly illustrated that the proposed protocol achieves a low end-to-end delay with multiple sources.

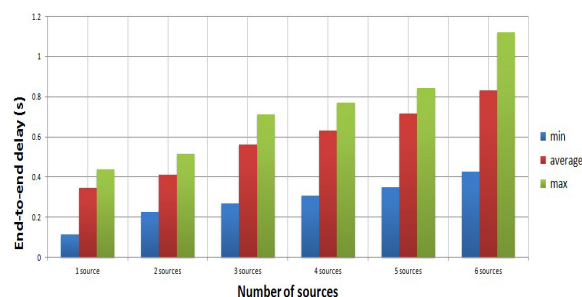


Fig. 6. End-to-end delay of the proposed protocol with different traffic loads that the number of sources varying from 1 to 6, each source sends the packets every second.

The proposed algorithm also considers the delivery success ratio (DSR). It avoids data collision because in each timeslot only one node can send the packet. By means of this strategy, it can achieve high reliability. Additionally, while selecting the optimal forwarder, the node calculates the forwarding probability by considering the packet loss ratio. Fig. 7 shows the delivery success ratio of the three algorithms with different sources. From the figure, it can be seen that, as the number of sources increased (equal to higher traffic load), the delivery success ratio is decreased. The DSR decrease is induced by the packet collision, busy channel probability and network congestion. However, the delivery success ratio of the proposed protocol is highest than the other algorithms. The strategy of the proposed protocol achieves a high reliability communication, which contributes to the good performance of the proposed protocol. The delivery success ratio of THRG is almost the same with the proposed algorithm. Because the formula to calculate the

forwarding probability in proposed algorithm is the same as THRG used. Both of them considered the packet loss ratio. However, the Dijkstra algorithm did not consider any reliability strategy, thus its performance in delivery success ratio is low.

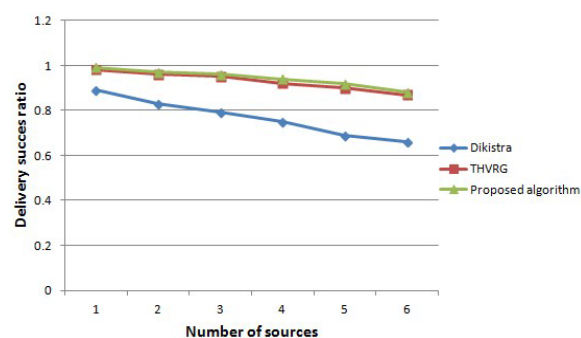


Fig. 7. Delivery success ratio of three protocols with different sources, each source sends the packets every second.

5.1.2. Number of Hops and Delay

The number of hops is an important factor that affects the end-to-end delay of the protocol. Thus, in this section, the paper considers the number of hops to evaluate the performance of the proposed algorithm.

Fig. 8 shows the delay for three algorithms varied from different number of hops. When the number of hops increases, more delay will be caused because more hops require more timeslots. It can be seen from the figure that the proposed algorithm outperforms other considered algorithms. In the proposed algorithm, it simplified the topology of the network and optimized the number of timeslots for TDMA scheduling, as described in section 4.1. Thus, it can reduce the number of waiting timeslots which will result in a less delay. THVRG has a better performance than Dijkstra algorithm, because it optimizes the number of relaying hops while Dijkstra only considers the number of hops which will cause a lot of traffic loads so that some nodes require more time to get the chance to send the packets.

Fig. 9 shows the average delay comparison between emergency data and regular data with 1, 2, 3, 4, 5 hops in different sized network. As the figure displays, as the number of hops increase, the average delay increases regardless of the size of network is 10 nodes or 20 nodes and the packet is emergency data or regular data. This indicates that more hops will use more time slots to relay the packets and even wait for a longer time to get the chance to send it. If we compare the difference between emergency and regular nodes in these two different size networks, it is conspicuous that the difference will be larger for more hops and even for more nodes. This implicates that the discrepancy between emergency and regular packets for increasing number of hops in different size network is not proportional increase. As the

result confirms, the average delay for emergency data is less than the average delay of regular data in different number of hops and different size network.

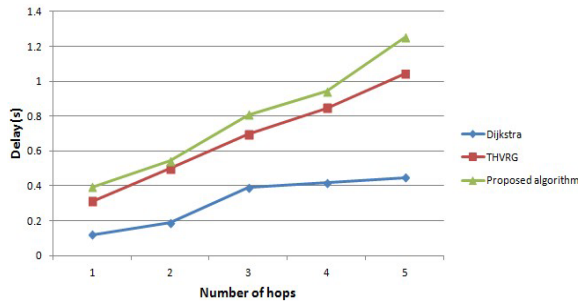


Fig. 8. The delay of three protocols with different number of hops.

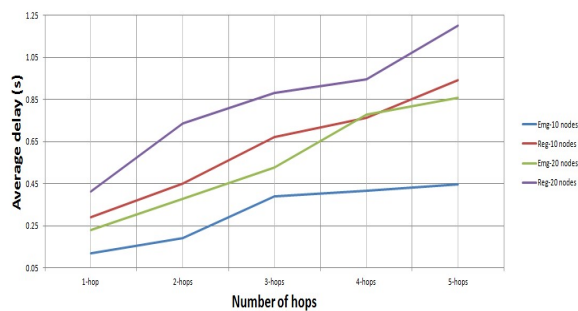


Fig. 9. Average delay comparison between emergency data and regular data with different number of hops in different size network.

6. Conclusions

Industrial Wireless Sensor Network (IWSN) applications are attempting to achieve the new requirements such as real-time delay, reliable delivery, etc in industrial environments. Based on the significant economical investments and benefits, the security of industrial environments is important. The sensors monitor the environment and when an emergency situation is detected, the sink will be notified so that it can cope with it.

In this thesis, a TDMA-based real-time delay routing with two-hop neighbour information in IWSN is proposed. The goal of this thesis is to achieve real-time delay and reliable delivery. Two-hop neighbour information is used to calculate the two-hop velocity, which has been adopted in a number of existing protocols, and it has been proven that it can reduce the end-to-end delay. To guarantee the real-time delay of emergency data, the packets are classified into two categories: emergency packets and regular packets. The priority scheme is implemented in the priority queue model where the emergency packets will always be given the highest priority to go forward. In the proposed protocol, TDMA is adopted to guarantee a deterministic timing constraint for real-time communication in industrial applications.

The proposed protocol is simulated by using the OPNET Modeler and is mainly evaluated from two aspects: end-to-end delay and delivery success ratio. The performance of proposed protocol shows a low end-to-end delay and high delivery success ratio. The proposed protocol is also compared in relation to the emergency and regular packets in different sized networks. It illustrates that the delay of emergency packets is less than that for the regular packets.

Thus, from all the results of the evaluation, it can be determined that the proposed protocol achieves real-time delay and reliable communication in an IWSN. However, in future work we need to think about dynamic network and also consider the energy consumption. And to optimize the TDMA scheduling is also important aspect to improve the algorithm.

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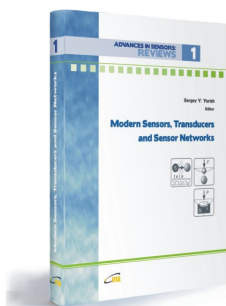
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1

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