DYNAMIC ROUTING PROTOCOL AND DELIVERING SCHEME FOR MULTIEVENT WIRELESS SENSOR NETWORK

Nguyen Thi Thu Hang, Nguyen Chien Chinh, Nguyen Tien Ban
Telecommunications Department 1
Posts and Telecommunications Institute of Technology, Hanoi, Vietnam

***Abstract*—In multievent wireless sensor networks (WSN) like smart kindergarten, forest fire alarm system, environmental monitoring system, industrial automation, events have different QoS (Quality of Service) requirements such as reliability, latency. Most of researches in this area have just dealt with one or two QoS requirements or one QoS requirement with several priority levels or with limited types of events, there has not been any research supported multi QoS requirements for multievent WSN. This paper proposes a new solution to meet the new and diverse requirements for multievent WSN called DRPDS. By combining dynamic routing protocol and packet delivering scheme, our proposed solution enables multievent WSN support multiple QoS requirements such as latency and reliability. Our new protocol is implemented in OMNET++, the results show that in our study cases of three event types with different channel packet error rate per hop values, it can dynamically adapt to the different QoS requirement events simultaneously occurring in the network, and achieve better QoS in term of latency (about 20% lower) for lower latency requirement events and packet error rate (about less than 1%) for higher reliability requirement events than other coexisting events.**

Keywords—dynamic routing, event driven routing, QoS, multievent, wireless sensor network.

I. INTRODUCTION

Wireless sensor networks (WSN) have been an important research area recently because of it usability and vast applications [1], [2]. Wireless technologies and Micro-electromechanical systems have enabled for the implementations of variety WSN applications in military, transportation control, healthcare, environment monitoring, and, in the IoT world, sensors are among the essential elements. They build up smart homes, smart kindergartens, and smart hospitals … in smart city. Due to the individual characteristics of WSN such as large number of sensors, limited capabilities, processor and power, continuity change of topology accompany with the multiplicity of application's requirements have pushed on many challenges for researchers. To deal with the requirements, there have been different proposal solutions: data compression and aggregation [3], [4], clustering [5], MAC protocols [6], energy efficient routings [7], load balancing techniques [8] …

In multievent WSNs like smart kindergarten, forest fire alarm system, environmental monitoring system, industrial automation, there are many types of events with different requirements in communication quality such as reliability, latency, rate, priority, etc. [2], [9-15], but most of researches in this area have just dealt with one or two QoS requirements or one requirement with several priority levels, or with limited types of events, there has not been any research supported multi QoS requirements for multievent WSN.

Many routing protocols in WSN have been designed as single path protocol where the source node selects a single path to send sensed data toward the sink node [16], [17]. Although the work of finding a single path is simple with low computational complexity and minimum resource utilization, it could react slowly with the rapid change in the network topology (node or link failure) and can not support reliability as required caused by limited capacity of a single path. So, many multipath routing protocols have been researched and developed to overcome the disadvantages of the single path routing protocols [18-21].

Based on the employed path selection and traffic distribution mechanisms, the multipath routing protocols can be divided by two types: alternative multipath routing and concurrent multipath routing. The alternative multipath routing provides energy-efficient and reliable data transmission, however it suffers from the main disadvantage of the alternative path routing strategy: the end-to-end capacity is limited to the capacity of a single path, so most of the recently proposed multipath routing protocols utilize concurrent multipath routing to support even traffic distribution (to balance resource utilization) and provide the required bandwidth of high-rate applications [18]. On the other hand, in some cases multipath routing in wireless sensor network does not meet the desired quality or not improve single path transmission: (1) Source has only one neighbor towards the destination, so multipath can not be effective. (2) There are few forwarding nodes near the sink cause the paths to converge at the front of the sink and cause congestion (now the multiple paths are not disjointed but braided).

This paper proposes a novel solution to meet the new and diversity requirements for multievent WSN called DRPDS (Dynamic Routing Protocol and Delivering Scheme): to choose suitable routing criteria for events in WSN accompany with the load sharing and redundant transmission schemes. We implement it in OMNET++. The simulation results show that, the protocol can dynamically adapt to different events simultaneously occurring in the network and support different requirements in terms of latency and reliability.

The rests of the paper are organized as follows: Section II discusses the related work. Section III introduces our proposed multipath routing protocol DRPDS and its mathematical theory analyses on reliability and delay. Section IV presents the evaluation of our protocol based on computer simulation. Finally the last section is the summarization and our future research work.

II. RELATED WORK

Recently, there have been several researches on multipath routing protocol based on the path selection and the importance of the collected data to achieve various performance benefits.

In [22], a novel multipath routing protocol is presented, it increases reliability by using multiple paths and scheduling data transmission rate at each node. This approach helps to avoid congestion and packet loss. Every packet is assigned a priority number based on the information it has. Each node has two queues for incoming data and three queues for transmitting the data. All nodes in the network act as a scheduling unit and put the arriving packets in the appropriate queue. Then, the node will select the packet based on the priority number from the queue and schedule a transmission to its next available multiple nodes. This protocol controls the network traffic by adjusting the queue length. On the other hand, the routing protocol has not considered the delay of packet and requires the complex queuing capability.

In ReInForM (Reliable Information Forwarding Using Multiple Paths [23]), the source sends multiple copies of the same data through multiple paths to the sink. Each packet is assigned a priority level based on the content of the information it contains. The source computes the number of paths (or equivalently, the number of copies of the packet to be sent) based on the importance of the information, local channel error and distance from the sink. ReInForM does not distinguish between the actual source and an intermediate forwarding node. Next hops are usually chosen among the nearest hops to the sink, otherwise they would be chosen randomly. This helps in load balancing and avoids the nodes on the "better" path to be quickly energy depletion. However, sending multiple copies of all packets would waste energy and the routing protocol had not considered the latency of the event.

In [11], the multipath routing protocol is proposed in which the sink discovers paths based on path weight factor by using link efficiency, energy ratio, and hop distance. The sink selects the number of paths among the available paths based upon the criticalness of an event, and if the event is non-critical, then single path with highest path weight factor is selected, otherwise multiple paths are selected for the reliable communication. So this research has just differentiated two types of events and the discovering path is initiated from the sink.

In [21], a multipath routing algorithm is proposed that could support reliable data transmission in a WSN. The proposed algorithm also take care about the constraints of the energy consumption according to the sensor node components and the distance that separate each node to another one. But this research has just deal with one type of events and has not considered the delay of packet.

From the above analyses, it can be seen that all of these researches have just dealt with only one or two QoS requirements and/or several priority levels, there has not been any research supported diversity QoS requirements for multievent WSN.

Our proposal in this paper is to discovering paths and use dynamic load delivering scheme which adapt to the three types of events, consequently it supports better performance for different event requirements of reliability and latency in multievent WSN.

III. DRPDS PROTOCOL

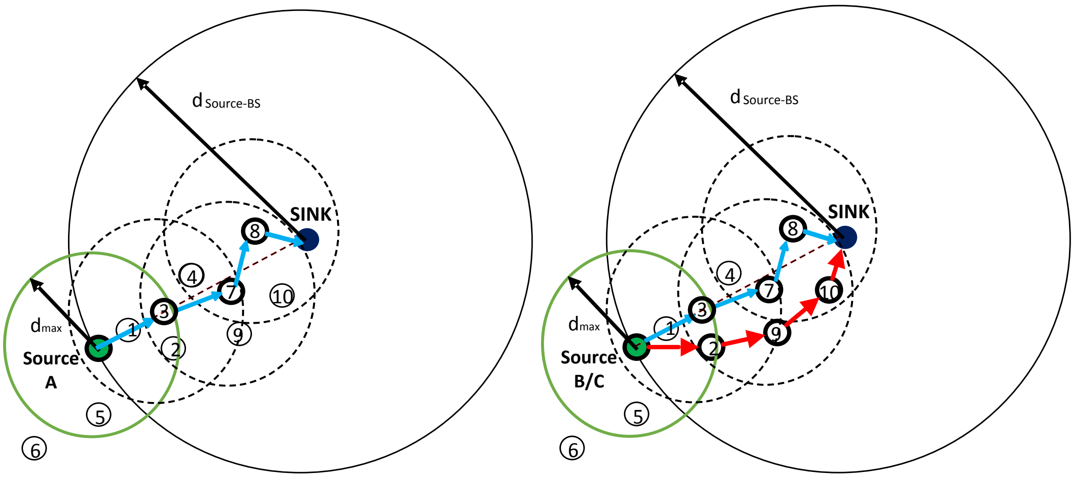
Based on the requirements of WSN applications and the benefits of multipath routing protocols, we propose a novel dynamic routing protocol for WSN called DRPDS which adapts to different event requirements of the latency and reliability.

Our event-driven dynamic protocol considers three types of event for WSN with three different levels of reliability and latency. To save energy for the event-driven network, the path discovery phase is initiated with the appearance of event and starts from the source node, only in-range nodes for the task of forwarding the data packet would be chosen to deliver data packets and should be as close to the base station (sink) as possible.

Fig. 1 shows a scenario of the protocol. Source node type A has to find one best neighbor among the sink-nearer ones to deliver its sensed data packets. There are four neighboring nodes (1, 2, 3, 5) of the source in which only three nodes are alive sink-nearer (1, 2, 3). Among these, there is one that alive and nearest to the sink (node 3). So, source node would choose node 3 to be the best relay node on the routing path to the sink. Then if source node type B or C needs two paths to deliver the sensed data packets, it will choose nodes 3 and 2.

In addition, the criteria for finding paths and forwarding data packet are designed to adapt with the differentiation of many events as follow:

- Event type A: When this event occurs, single path routing is chosen to save energy and because this event does not require high reliability and latency (not too urgent).
- Event type B: When this event occurs, multi path routing should be chosen because this event requires higher reliability. In our protocol, two paths are chosen to forward the messages instead of flood the messages to all its neighbors. By doing that, the reliability is increased and the number of forwarding messages is reduced. All messages from source nodes should be copied and forwarded over two paths simultaneously.
- Event type C: Can be used in the case of the highest level of urgency. Multi path routing should be chosen similarly to the event type B. This type of event should have lowest latency because of the event urgency. To support the requirement, messages should be sent over two paths using a load sharing scheme.



a) Event driven single path distant routing *b) Event driven multipath distant routing*

Hình 1. Event driven shortest distant single path and multipath for multievent wireless sensor network.

A. Network Model

The WSN can be viewed as an undirected graph $G=\langle V,E\rangle$ where V represents the set of vertices (sensor nodes and sink) and E represents the set of edges. We assume there are N sensor nodes randomly place in an area ($M\times M$ m^2), there exists a link $E(i,j)$ between node i and node j if the Euclidean distance $Euclidean(i,j)$ is not larger than the sensor node's radio transmission radius (d_{max}). There is a single monitoring node (sink), it is in fixed position and has unlimited power, it knows its position and all nodes' position. When sensor node detects an event, it will send its data directly to the sink if its distance to sink is less or equal to its vicinity or indirectly over its neighbors otherwise.

B. Proposed Operation

Fig. 2 shows our proposed operation of multievent wireless sensor network. Sink calculates the distance to all nodes in the sensor fields and the distance from a node to all of its neighbors in its vicinity. Then sink will deliver information of the distances and nodeID of a node's neighbors to every node. Based on this information, each node, upon detecting an event, will send request messages to its neighbors and get reply packets with the information of neighbors' remaining energy.

Based on the type of the event, sensor node will decide the number of paths and the delivery scheme for the data of that event.

- If the distance to sink is equal or less than d_{max} (the maximum transmission range of sensor), then node sends data directly to the sink (node does not have to build routing table, neither care about the event type).
- If not, sensor node will have to find out the alive neighbors that could transfer its data to the sink. One or two best neighbors will be chosen based on the distance to the sensor node and the distance to the sink, as far the source node and as close to the sink as possible (that is the shortest path in term of distance or hop count). There are three cases

for the routing and delivering event packet (Fig .2).

C. Theory Analyses

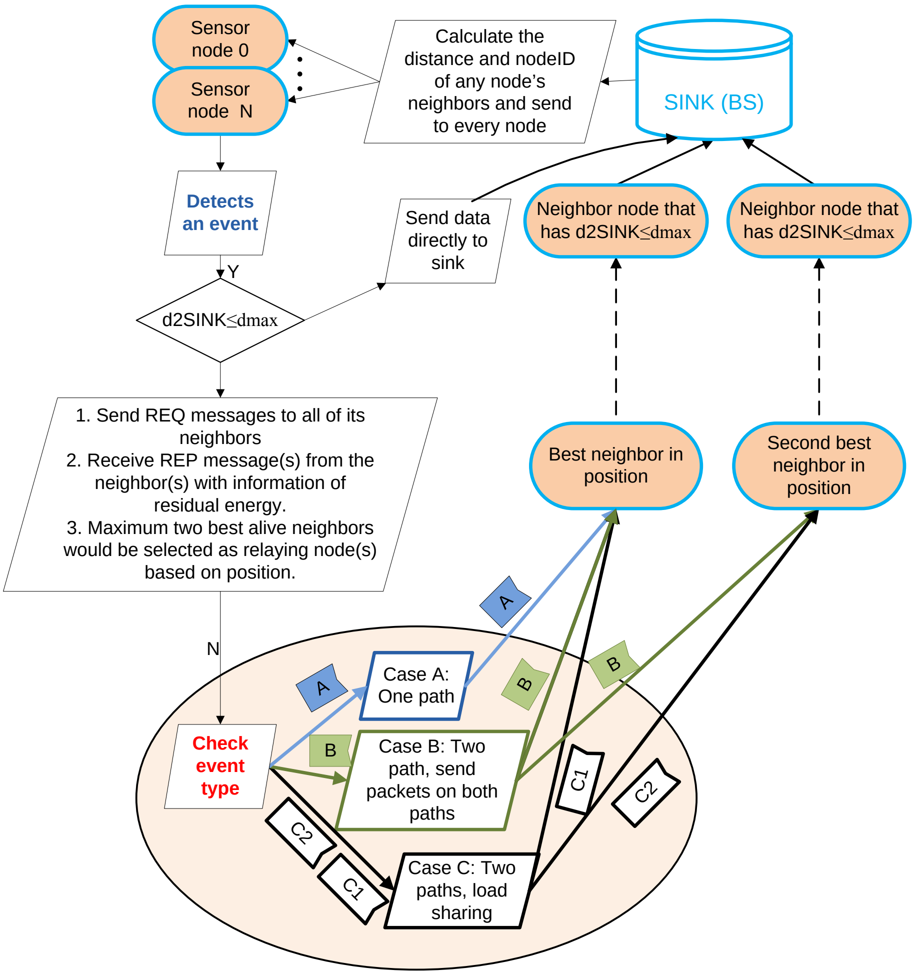
In this section, we address the probabilistic formulation of reliability and analyze packet delay for both single-path and multi-path routing. The results show that multi-path routing with redundant transmission is effective in improving the reliability and load-sharing on multipath would reduce the queuing time of packets, then reduce the packet delay in simple way.

1) *Reliability analysis*

If the number of original packets sent by the source is N_S, and the number of distinctive packets received by the sink is N_R, the reliability, denoted as R, is $R = N_r / N_s$. Here the distinctive packet means that if sink receives multiplicative packets (the original data packet and the copy one), it considers those as one received packet.

a) Reliability of Single-Path Routing

Consider a source and a sink which are h hops apart. Let the per hop channel packet error rate (PER) at j^{th} hop in the path across the entire network be a variable e_j^c (where $0 \le e_j^c \le 1$), and it is proportional to the distance), then the perhop reliability at j^{th} hop is $(1-e_j^c)$.



Hình 2. Operation of DRPDS in multievent wireless sensor network.

The reliability of a path is a multiplicative metric. Thus, the probability that packet is received by the sink over a single of h hops apart, $p(h)$, is

$$p(h) = \prod_{j=1}^{h} \left(1-e_j^c\right) \tag{1}$$

Then single path packet error rate in this situation is

$$PER^{single} = 1 - p(h) = 1 - \prod_{j=1}^{h} \left(1-e_j^c\right) \tag{2}$$

Thus, in a multihop sensor network, where channel errors could be very high and a source could be far away from the sink, a naïve forwarding scheme will result in a high PER, so single path routing is in capable of attaining good reliability.

b) Reliability of Multipath Routing

In multipath routing, if there are L paths and the hop count of the i^{th} path is h_i, the multipath packet error rate in this situation is the probability that all copy packets would suffer error in all L ways and can be calculated as

$$PER^{multipath} = \prod_{i=1}^{L} PER_i^{single} = \prod_{i=1}^{L}\left[1 - p_i\left(h_i\right)\right] = \prod_{i=1}^{L}\left[1 - \prod_{j=1}^{h_i}\left(1 - e_{i,j}^{c}\right)\right]$$

(3)

where $p_i\left(h_i\right)$ is the probability of success for the i^{th} path defined in Eq. 1 and $e_{i,j}^{c}$ is the probability that a packet is dropped at the j^{th} hop of the i^{th} path.

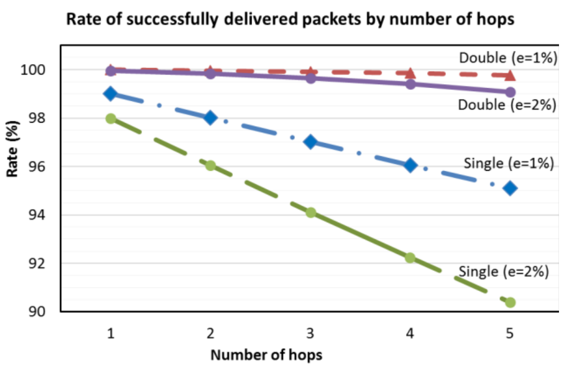
Then, the probability that at least one copy of a packet is successfully received by the sink over L paths, $p\left(L\right)$, is

$$p\left(L\right) = 1 - PER^{multipath} = 1 - \prod_{i=1}^{L}\left[1 - \prod_{j=1}^{h_i}\left(1 - e_{i,j}^{c}\right)\right]$$

(4)

Packets may be lost due to channel error and queue overflow; in such cases, sending multiple packets on multiple paths will improve the reliability or reduce PER.

Fig. 3 is a specific example for the mathematical reliability evaluation of single-path and two-path routing with a PER of 1% and 2% dropping on a hop. As we can see, the higher the number of paths the better the reliability, and the larger the number of hops, the higher the PER.



Hình 3. Reliability evaluation based on the number of hops, paths, and perhop channel error rate.

2) *Latency analysis*

The total delay, denoted as d, experienced by a packet in a path of hop count h is the sum of the delays at the intermediate nodes, d_j (where $j = 1, 2, ..., h$), and is given by

$$d = \sum_{j=1}^{h} d_j$$

(5)

Considering the propagation and processing delays as negligible, d_j can be calculated as follows

$$d_j = d_{trans} + d_{MAC} + d_{que}$$

(6)

where d_{trans} is the transmission delay, d_{MAC} is the medium access delay and d_{que} is the queuing delay of a packet.

In this paper, we concentrate into the queuing delay of a packet. Queuing delay at any node depends on the queue service time and the packet arrival pattern.

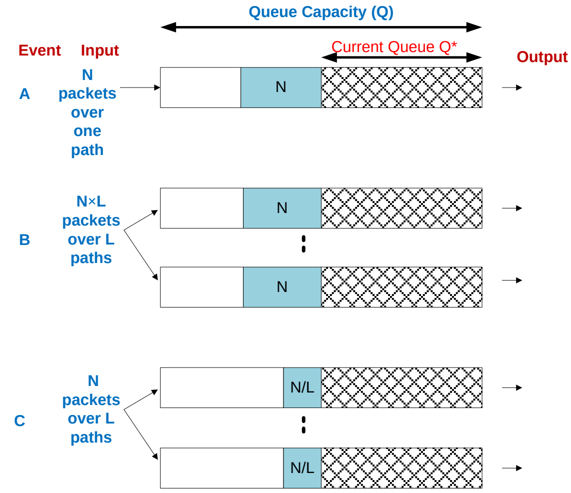
Fig.4 shows the analysis of the queuing delay of packets, we just compare the queuing delay of packets over single and multiple paths using redundant transmission and load-sharing schemes (as proposed in Section III.2).

From source nodes, there are three event type packets would enter queues with the current queue length of Q* packets over a maximum capacitor of Q packets. As we can see from the figure, for event type A and B packets, there are only N packets would be sent over one path, so the average queuing delay of packet type A and B is equal, of type C is less and proportional to the inversion of L - the number of paths, they can be calculated as

$$d_{queA} = d_{queB} = (Q^* + N/2) \times d_{service} \tag{7}$$

$$d_{queC} = (Q^* + N/2L) \times d_{service} \tag{8}$$

From Eq. 7 and Eq. 8, it is clear that sharing data packet to transmit over multiple paths, the load placed on each link decreases, thus reducing the packet processing time. If the queue is almost fully, then packet loss rate will increase in case of event type A and B more than event type C.



Hình 4. Occupation of queue for the three event types.

3) *Complexity and overhead cost*

In our method, we have defined three different packet types, so the imposed overhead makes the source node waste more energy to clarify the packet type before sending event packets.

As transmitting multiple copies of data packets increases delivery reliability, the proposed method for event type B would consume more, that is a trade-off between energy consumption and reliability.

For event type C, the proposed scheme must be more complex to split the traffic on two paths. In return, this technique helps balance energy usage and provides better latency for packet over congested path.

IV. PERFORMANCE EVALUATION

A. *Simulation Parameters*

Table I presents some of key parameters used in our OMNeT++ simulation [24]. There are numerous events occurring in the sensor network, they can be classified into 3 types A, B and C, and can appear simultaneously so that there is competition for resources like bandwidth and queue. The events appear 100 rounds with 20 events occurs in random manner per round, in order to avoid special circumstances in our simulation (that has been mentioned in Section I), it is necessary to place the traffic sources at a reasonable distance to the sink, at the rearmost of the sensing area (Fig. 5). Channel packet error rate is set up to 1% and 2% per hop, except the last hop from node to sink the error rate is given as zero because of the good signal receiving power of the sink. The traffic loads in all scenarios are equivalent (ratios of a number of packets per event to time intervals are constant). In each round of 0.16 seconds, there are 20 nodes sending 10 packets/event at random time with data packet size of 128 bits, so the total average traffics of network are 160 kbit/s. The traffic comes from the four rears of the sensor network, so at some times it might be converged before reaching the sink, so there would be congestion (link bit rate is 30.720kbit/s) and at those times the C event types would take advantage of less latency.

Bảng I. SIMULATION PARAMETER FOR DRPDS

Parameter	***Value***
Number of sensor nodes	100
Network size	500m x 500m
Sensor node's radio transmission radius (d_{max})	120m
Number of packets/event (burstLength)	10, 20, 40
Time interval (for one round, in seconds)	0.16, 0.32, 0.64
Data packet size (DATA)	128 bits
Link bit rate	30.720 bit/s
Sink position	(250m, 250m)
Queue size (Data packet)	120-200
PER of one hop (e^c=0 - 2%)	(10 - rand(0,1)) * $(d / 120)^2$ /10*e^c

The following performance parameters are assessed in the simulation:

- Packet Error Rate: It is a ratio of loss packets to packets sent. For event type B, because there are copy ones, the loss packets are the packets that unsuccessfully travelled over even one or two paths and the packets sent are the original ones (not the copy packets). It is expressed in term of percentage.
- Delay: It is the total time taken to deliver the data packets from event nodes to sink node. It is expressed in term of millisecond.
- Delay advantage of C over A: It is the differences in time of the C packet delay over A one, it is expressed in term of percentage of the differences of delay value over the average delay value of the two packet types.

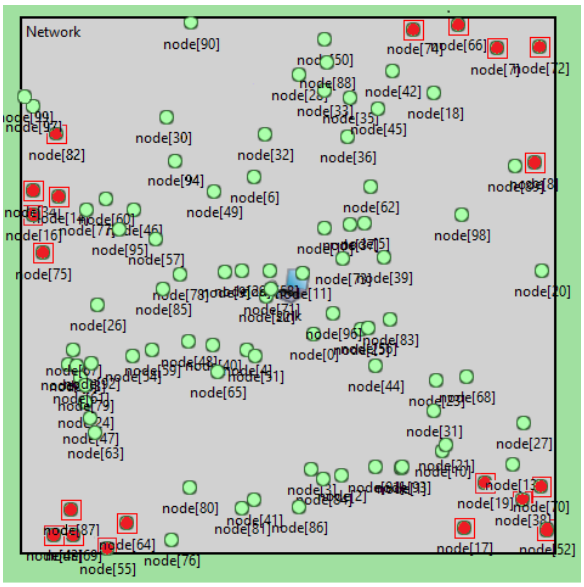


Fig. 5. Simulation network topology

B. *Result analyses*

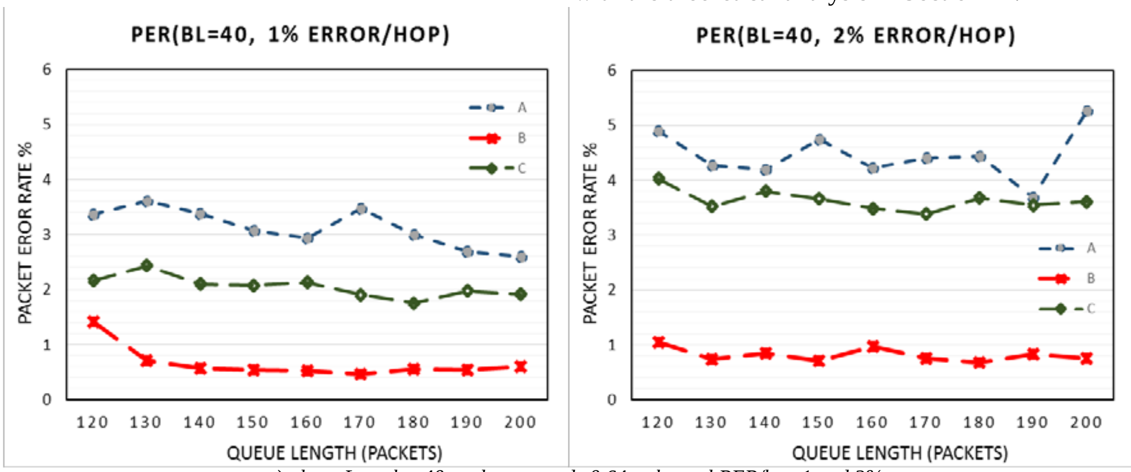
In this section, simulation results show that our routing protocol could adapt to the three event types with different QoS requirements when there is competition for traffic.

1) *Packet Error Rate*

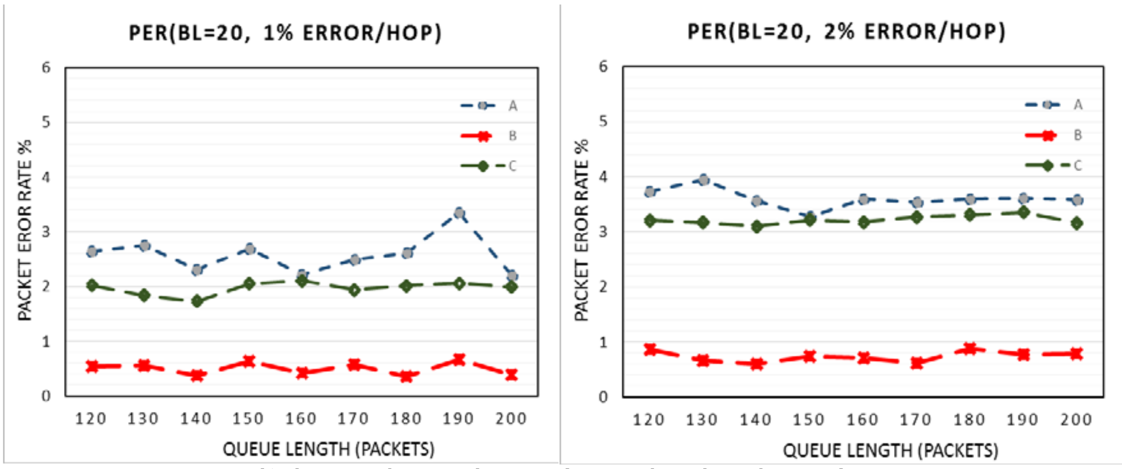
Fig. 6 shows the result in PER of our simulation. It can be seen that the PER of event B is significantly improved compared to the other two events, namely the B's PER has dropped to less than 1% when the queue was large enough (in addition to 120 packets) while the PERs of A and C were less than 4 and 5 % when channel packet error rate is set up to 1% and 2% per hop.

PERs of event B and C are higher with higher channel packet error rate. The PER of C is just better than A's PER when there is congestion (bL=20 and 40), but the packets of C go on two paths and only one optimal path is identical to A, the other path is not as good as the first one and the PER is also higher on the second longer path. So, in most cases, the difference in PER between A and C is not significant.

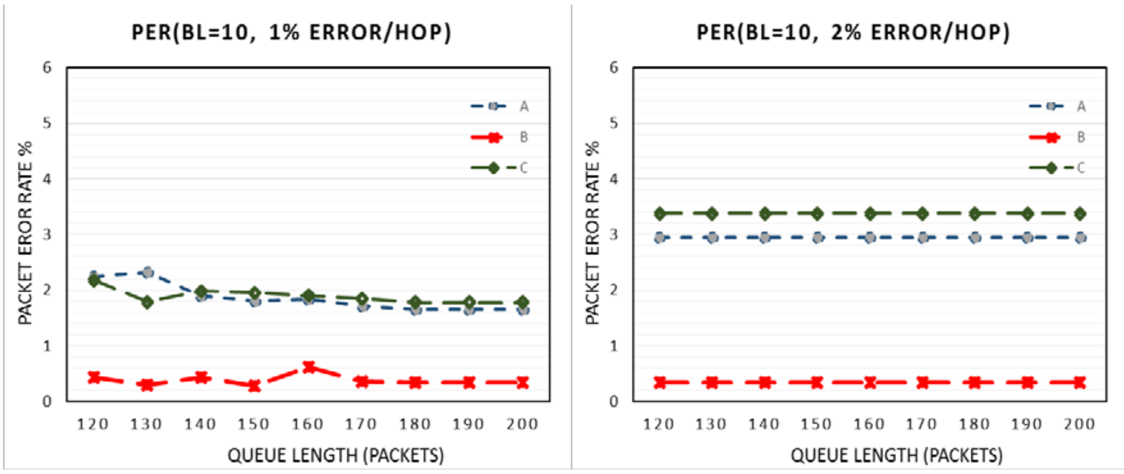
The larger the queue, the lower the packet error rate, though B sends packets on two paths in which one is not as good as the other path, but it can reduce congestion on a path and sending a copy packet would decrease the packet error rate at the sink, because it requires only packets arriving at the destination on one of the two paths successfully. This result is consistent with the theoretical analysis in Section III.



a) burstLength =40 packets, round=0.64s, channel PER/hop 1 and 2%



b) burstLength =20 packets, round=0.32s, channel PER/hop 1 and 2%

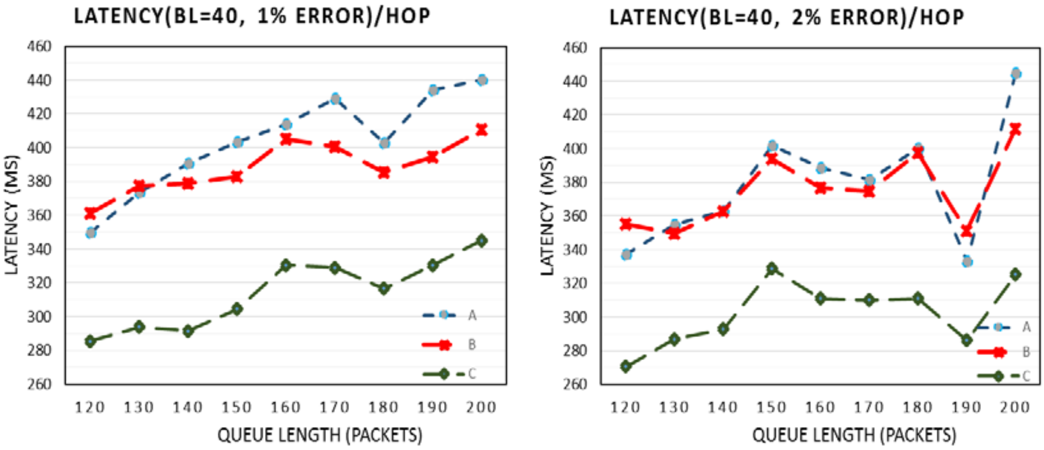


c) burstLength =10 packets, round=0.16s, channel PER/hop 1 and 2%

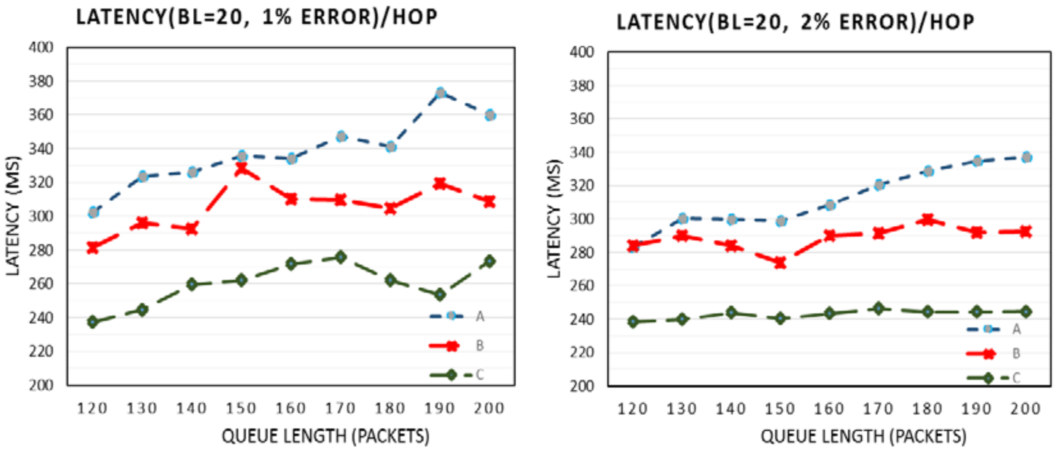
Fig.6. Comparison of Packet Error Rate of three event types (A, B, and C) in 200 rounds, all events occurred in random manner with equivalent ratio of traffic load.

2) *Latency and Latency advantage of C over A and B*

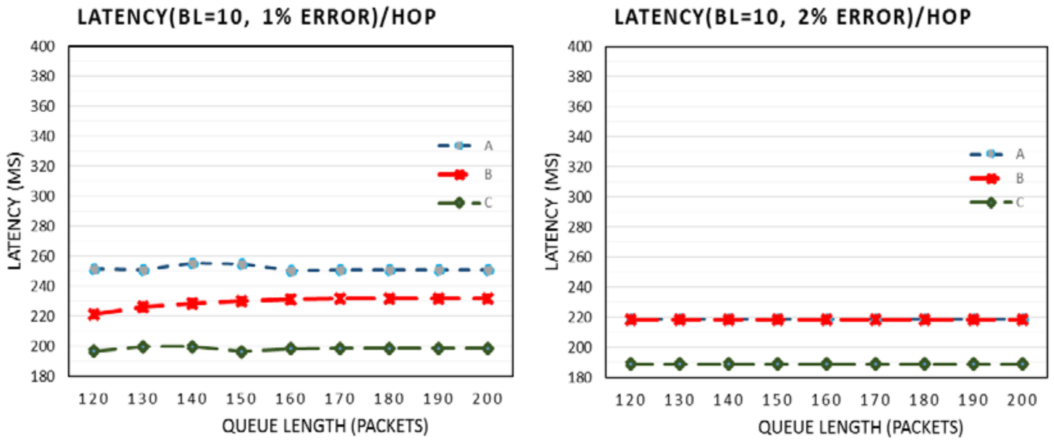
Fig. 7 shows the result in Latency of our simulation. It can be seen that event C's packets have the smallest average latency. The latency of C significantly improved over that of A (from over 15% to over 30%, depends on the queue's usage), because the packet of event C could split on two paths so the number of C packets on one path is reduced to half compared to A and B's packet, so C less congested than A and B, and they are easier to enter the queue than the others packet types.



a) burstLength =40 packets, round=0.64s, channel PER/hop 1 and 2 %



b) burstLength =20 packets, round=0.32s, channel PER/hop 1 and 2%



c) burstLength =10 packets, round=0.16s, channel PER/hop 1 and 2%

Fig.7. Comparison of Latency of three event types (A, B, and C) in 200 rounds, all events occurred in random manner with equivalent ratio of traffic load.

V. Conclusion and Future Work

A. Conclusion

This is the first research work that supports multi QoS requirements for multievent wireless sensor network. The proposed DRPDS routing protocol for multi-event wireless sensor networks is implemented in OMNET++. The simulation results show that in terms of resource diversity, it significantly improves data packet delay (even more than 30% in case of congestion) compared to single-path routing by splitting data over multipath, and by by sending redundant data it would significantly reduce packet error rates (about less than 1%) for high-reliability required B events while the PERs of A and C were less than 4 and 5 % with different channel packet error rate per hop of 1 and 2%, so the protocol has met the diversity requirements of the multi-event wireless sensor networks. However, the results also show that if one event needs many QoS requirements in order of priority, the algorithm has not met yet, namely C has the best latency, but its PER is not the best as well, B is best for PER but the delay time is greater than the other two events.

B. Future Work

In the future, we will continue to improve the quality of communications for multi-event sensor networks based on priority queues so that they can better prioritize events that require high priority on latency and reliability.

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Nguyen Thi Thu Hang received Electronics and Telecommunications Bachelor's degree from Hanoi University of Science and Technology Vietnam in 2000, Telecommunications master's degree from AIT, Thailand in 2003. Currently working as lecturer and PhD student at Posts and Telecommunications Institute of Technology. Areas of study: Communication networks, Wireless sensor networks, QoS routing.

Nguyen Chien Trinh received master's degree in 1999 and PhD degree in 2005 from the University of Electrical and Information Engineering, Tokyo, Japan. He is currently the Head of Department of Telecommunication Networks, Faculty of Telecommunications, Posts and Telecommunications Institute of Technology. Fields of interest include Next Generation Networks, QoS Assurance, QoS routing, traffic engineering, SDN.

Nguyen Tien Banreceived master's degree at the Leningrad University of Electronics Engineering (LETI) in Russia, PhD degree from the National Telecommunications University (SUT) in 2003, associate professor in 2012. He is currently Dean of the Faculty of Telecommunications, Posts and Telecommunications Institute of Technology. Fields of interest include Network Performance, Network Design and Planning, Telecommunication Networks Modeling and Simulation.