

Optimizing Reliability through Network Coding in Wireless Multimedia Sensor Networks

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Abstract

One of the remarkable challenges in the area of Wireless Sensor Networks (WSNs) is how to route the collected data and transfer them in the nodes. Due to the high rate of packet loss, guaranteeing reliable and efficient packet transfer and delivery is considered to be one of the hot issues in the area of WSNs. Indeed, due to energy limitation of nodes in WSNs, reliability and energy are regarded as critical parameters in these networks. In this paper, a method has been proposed for optimizing the parameters of reliability and energy consumption in multimedia WSNs. In the proposed protocol, Increasing the Delivery Ratio with Network Coding (IDRNC) a network coding mechanism has been used for transmitting data which enhances the reliability of the network. Furthermore, reducing the number of transmissions and receptions in network nodes results in the reduction of energy consumption. In the proposed protocol, the transmitted packets are first coded and transmitted to the sink through the shortest route. In the middle of the route, in case packets are lost, median nodes can detect and recover the lost packet through the coded packet. The simulation results indicated that the method proposed in this study operates better than the LIEMRO method with respect to the following features: system efficiency, average remaining energy of the network, the number of lost packets and reliability.

Keywords: Multipath Routing, Network Coding, Reliability, Wireless Multimedia Sensor Networks (WMSNs)

1. Introduction

In recent years, the application of WSNs has developed extensively in a variety of areas which range from industry, environmental monitoring, target tracking and detecting, monitoring and controlling patients' conditions, etc. In WSNs, sensor nodes receive the environmental data through the available nodes in their architecture; then, after it processes the received data primarily in the node, the sensor nodes transmit them towards the target. The connections and communications among the nodes are wireless and they interact with their physical environment. In WSNs, the limitations of sensor nodes such as battery energy, transmission rate, processing hardware and memory combine and interact with the specific operational context and hence, practically define and

produce the two significant parameters of reliability and energy efficiency. On the other hand, data security is a significant parameter. It can be argued that more research studies should be conducted in the area of energy efficient routing¹⁻³.

In WSNs, sensor nodes receive the data related to the environment via their available sensors in their architecture, conduct a primary processing on them and transmit them to the target. The nodes communicate with one another wirelessly and interact with their surrounding context. In as much as WSN nodes use battery, their energies are limited. Hence, designing routing protocols with the capability of enhancing network lifetime and ensuring the required degree of reliability for transmitting packets is one of the critical issue in WSNs. Using multipath transmission methods is one of the solutions for

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enhancing reliability of these networks^{1,4,5}. For ensuring the reliability of packet transmission, numerous methods have been proposed:

- Using the method of data delivery confirmation and retransmission of corrupted packets.
- Using the methods of channel encryption by data redundancy.
- Packet redundancy which refers to the transmission of multiple copies of a piece of data through a secure route.
- Path redundancy which refers to the identical transmission of data through multiple paths.

However, it should point out that using these methods such as route redundancy results in an increase in the number of received packets in the target. That is, for achieving desired degree of reliability, multiple copies of a packet are transmitted to the target through multiple paths. On the other hand, due to energy limitations in these networks, using the multi-path method will lead to higher energy consumption in the network^{6,7}.

Numerous routing protocols have been proposed for multimedia WSNs which are aimed at successful and reliable packet transmission; the notable feature of these protocols is that they take energy consumption efficiency into consideration. As a matter of fact, it can be argued¹⁰ that selecting optimal route based on saving energy, enhancing packet transmission reliability and with respect to the numerous limitations of these networks such as energy resource, computational capability, memory, etc¹, are some of the outstanding challenges in WSNs. Indeed, there is a call for research on reliable network coding-based protocols. Network coding refers to a mechanism for enhancing reliability and reducing energy consumption in WSNs which was proposed by Ahlswede et al⁸. In general, network coding is conducted in two ways: linear coding and decisive coding.

The rest of the paper organized as follows: Section 2 introduces related works. Section 3 studies network coding scheme and its benefits. Section 4 shows proposed scheme. In section 5, we evaluated performance of proposed method and finally, section 6 concludes the paper.

2. Related Works

Several research studies have been carried out on energy efficiency in WSNs. Some studies have used topology

control for sorting out the energy problem⁹. Some other studies have tried to address this issue via controlling coverage¹⁰. Another mechanism devised for solving this problem is network coding which increases the degree of reliability and reduces the number of data transmission and reception; hence, it reduces energy consumption in the network.

Network coding was first proposed by¹¹. In this method, rather than simply transmitting just one packet, the mid node combines and integrates a few input packets into just one packet and then transmits that packet. In recent years, network coding technique has been used for maintaining reliability in WSNs. Network coding-based methods have relatively higher reliability than the traditional methods. Using this technique in multi-hop multi-cast networks results in the reduction of energy consumption¹². Coding linear data is a type of functional implementation of network coding¹³ introduced an error-tolerating routing mechanism for mesh networks which was based on network coding. Antonopoulos et al.¹⁴, proposed a protocol for Vehicular Ad hoc Networks (VANETs) which was based on *novel network coding* and *automatic repeat request (ARQ)*. This protocol was intended to reduce the number of the whole transmissions¹⁵ proposed a method in which a coding parameter (n, k) in proportion with the pollution status is selected. In this method, when a node detects an error in a packet, it does not eliminate the packet; rather, it sets a value for the syndromes of the error in the packet and then transmits the packet. It should be noted that this procedure will be done if the error is capable of being detected. After a sufficient number of packets are gathered, the secondary node will be able to recover the defective packet. Indeed, this method which is based on network coding has integrated the error detection and error recovery mechanisms with each other. In^{16,17} the authors found that in case network coding is used in underwater sensor networks, error recovery efficiency will be improved. Shaobin Cai et al^{3,17} proposed a novel protocol, called *Multi Paths and Network Coding (MPNC)*, based on network coding for enhancing packet delivery rate in this type of networks^{18,19}.

It is a protocol based on an event called LIEMO which is aimed at improving the quality of services in WSNs; it makes use of energy-efficient multi-path routing. The rationale behind this protocol was to improve packet delivery rate, network lifetime and reduce delay in transmitting packets to the sink based on multi-path discovery with the lowest degree of interference between the

resource node and the sink node. Moreover, this protocol uses a load balancing algorithm which distributes the traffic of resource node on multiple paths according to the relative quality of each path¹⁰. This protocol consists of three phases, namely initial phase, route discovery and diffusion phase and route-keeping phase. In the initial phase, each sensor node obtains data about its neighboring nodes; this operation is fulfilled through broadcasting a control packet. Route discovery and diffusion phase is accomplished when a set of data senses an event in the network which requires transmitting the packet of event to the sink node. This operation is performed via hop-by-hop route discovery and those nodes which follow the produced cost function are selected as the intermediate nodes. Route keeping phase also stores the discovered routes in its own buffer and keeps and uses them until it receives an error message indicating that the discovered route has been destroyed¹⁰.

3. Network Coding

One of the best and most effective proposed methods is the within-network processing which is based on network coding technique. The objectives of this technique are to reduce energy consumption and transmission traffic and enhance network life time and reliability in transmitting data in the network. As a case in point, consider Figure 1 which depicts a network with the three nodes A, B and C. Nodes A and B want to transmit the packets P_1 and P_2 , respectively but this transmission should be carried out through node C. In case network coding is not used for transmission, four data transmissions will be accomplished^{8,20}.

In contrast, in case network coding is used, node C will be allowed to combine the packets received from nodes A and B and transmit them; three transmissions will be required. Since node A holds P_1 , it can conduct the operation $(P_1 + P_2) + P_1$ by receiving $P_1 + P_2$; hence, it can

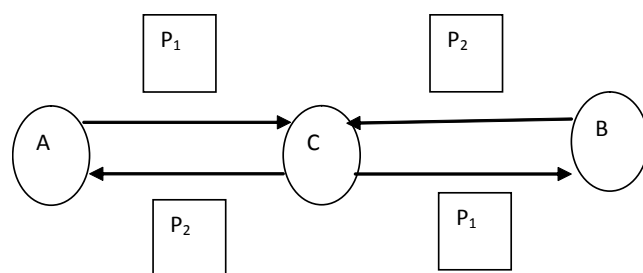


Figure 1. Transmission without network coding.

obtain P_2 . Summation operations in these calculations are based on summation calculations on the basis of two.

Using the network coding, it will be possible to combine and integrate the reception data of several routes with each other and transmit one packet in the network rather than transmitting several packets. This technique which was first intended to be used in WSNs gradually gained a good position among wireless network algorithms. Indeed, due to their inherent broadcasting nature, wireless networks can be regarded as a more appropriate context for the application of network coding than the wired networks. Network-coding aware routing refers to the fact that coding opportunities can be identified at the routing time and the route from the source to the target is selected with respect to the opportunities¹¹.

The butterfly network which is depicted in Figure 2 examines the coding method and its impact on enhancing reliability. In this figure, the resource S produces two packets x, y . the intermediate nodes A, B receive x and y packets respectively and retransmit them by the broadcast method. Having received the packets x, y , node C uses the $x \oplus y$ coding method to retransmit them. After receiving the packets $x, x \oplus y$, node D does the XOR process on them; hence, it can restore and recover the packets x, y . Therefore, in addition to receiving packet y , node E can receive packet x , too^{1,11}.

The application of network coding on the data to be transmitted in the communication networks has many benefits which are mentioned below.

Butterfly network, illustrated in Figure 2, enhances network efficiency which is the result of coding. Noting Figure 2 reveals that if intermediate nodes code different data, the degree of network throughput will be enhanced. That is to say, rather than the independent transmission of the packets P_1 and P_2 , by coding data P_1 and P_2 and transmitting a coded packet, it is possible to receive both packets in different nodes.

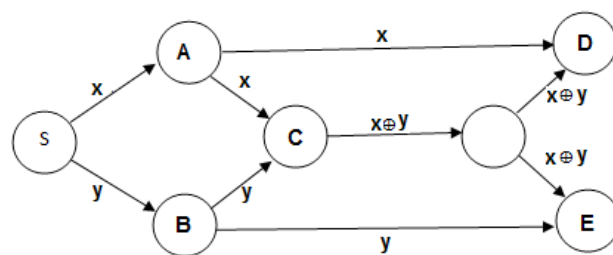


Figure 2. Butterfly network.

Using network coding, one can distribute the traffic load to the entire network. Figure 3 illustrates load balancing. As shown in this figure, the capacity of each communication link is 2 bps (bit per second).

It is assumed that the bits a and b originated from the source S and are transmitted towards the three targets R_1 , R_2 and R_3 . This coding feature prevents the heavy congestion on communication links and reduces the number of retransmitted packets and network delay¹¹.

In as much as bandwidth is regarded as one of the limitations of WSNs, it is essential that bandwidth be used optimally and efficiently. Network coding is one of the appropriate solutions for fulfilling optimal bandwidth use. In other words, by using network coding, it is possible to transmit more data on the network at any moment. Furthermore, it should be highlighted that optimal bandwidth use and network efficiency enhancement are interdependent^{21,22}.

4. Proposed Method

The protocol IDRNC includes four stages:

- Discovering route and calculating the distance between the nodes.
- Determining an appropriate neighbor node.
- Coding packet in the source node.
- Transmitting the coded packet.

Each of these four stages is described below.

4.1 Discovering Route and Calculating the Distance between the Nodes

In this stage, the entire network is identified by means of the Hello control packets; hence, every node discovers its parents, neighbors and children. In this way, the sink

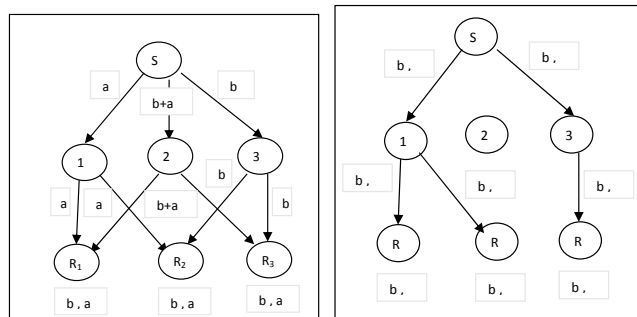


Figure 3. Load balancing by means of network coding.

distributes the Hello packet in which it has registered its address and the nodes receiving the Hello message identify the address included in the message as their own parents. Then, they register their own address rather than the previous address and broadcast it. The sink node receives these packets and identifies the address registered in them as its own children; in addition to parents, the other nodes which received the Hello packet from other nodes register their addresses as those of neighbors. Then, each node, after receiving the Hello packet and registering its address as parents, rebroadcasts it so as to identify its children and neighbors. This task continues until the Hello packets arrive at leaf nodes which have no children and it ends in them. In this way, the parents, neighbors and children of all neighbors are identified. In other words, it can be argued that all the nodes existing around a given node take one of the relations of being parents, neighbor or children.

In the method proposed in this study, the Hello message is used only for determining the required routes up to the sink. Response to the Hello message is given through Hello packets and the nodes do not use any explicit message. As a result, the number of control messages which are exchanged for determining the route between the nodes decreases. In this method, all the nodes occasionally update the list of their neighbors, children and parents via Hello packets so that they can use the list whenever they want to transmit a data.

$$d(i, j) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \quad (1)$$

In this equation, $d(i, j)$ refers to the Euclidean distance between nodes i, j . (X_i, Y_i) and (X_j, Y_j) refer to the geographical coordinates of the nodes i and j , respectively.

4.2 Determining the Appropriate Neighboring Node

In the method proposed in this paper, when a node has a data to be transmitted, at first, it measures the shortest route. The data required for calculating the shortest route include: the distance between two nodes (d), the remaining energy of the next node (R), weight parameter (α), the cost of selecting the next node $\text{cost}(i, j)$. For selecting the shortest route in the proposed method, two of the above-mentioned parameters are chosen and the cost of selecting the next node is obtained through Equation 2:

$$\text{cost}(i, j) = \frac{d(i, j)}{d(\max)} * \alpha + \frac{R_{\text{res}}}{R_{\text{ini}}} * (1 - \alpha) \quad (2)$$

4.3 Packet Coding in the Source Node

For coding packets A, B, the two packets A, B are first XORed with one another on the basis of two; then, the XOR of these two packets, which is called AB, is transmitted as the coded packet. With respect to the feature of XOR operator, whenever a coded packet is XORed with any of A, B packets, packets A, B can be obtained again.

4.4 Transmitting the Coded Packets

After determining the respective routes in the proposed method, the coded packets are transmitted towards the sink through this route. Indeed, the source node transmits the coded packet through the shortest obtained route. The format of the packet to be transmitted in the IDRNC method is illustrated in Figure 4.

The intermediate nodes which receive the transmitted packet continue to work by considering the same parameters so that the coded packet has priority over the non-coded AB packets in reaching the sink. In other words, the packet A remains a lower priority than the coded packet AB to be transmitted to the sink through the shortest route. Furthermore, the packet B has equal priority with the packet A but it is a lower priority than the coded packet AB in being transmitted to the sink. On the transmission path, each node including the packet A transmits a copy of the packet to the closest node which carries the packet B and each node including packet B transmits a copy of the packet to the closest node carrying packet A. Moreover, each node which transmits coded packets broadcasts a version of the coded packet to nodes A and B. Therefore, in case a node cannot, for example, transmit packet A to the next node, that node can obtain the lost packet again if it has the two packets B and AB. Thus, it significantly enhances the reliability (Figure 5).

5. Performance Evaluation of Proposed Method

The IDRNC method proposed in this study and the LIEMRO method were simulated in the Matlab 7.10 software. The protocols were compared with one another

Source ID	Ended data	Data ID	Group ID
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Figure 4. Format of the packet.

with regard to the following parameters: efficiency, system throughput, average remaining energy of the network, the number of lost packets, and the average length of the line of nodes. Table 1 shows simulation parameters and their values.

In addition to the parameters mentioned in this table, the impact of the number of produced packets and the initial energy of the nodes were examined and evaluated. Completely identical conditions were maintained so that the two protocols and their performance can be compared properly and accurately. Packet Delivery Rate (PDR) is obtained through equation 3 below:

PDR = (the number of delivered packets to the sink / the number of produced packets) (3)

The simulation was conducted at 5.000 rounds and the initial energy of the nodes was considered to be 5 Jules. Simulation parameters were mentioned in the table above.

System efficiency refers to the delivery rate of the produced packets delivered to the sink. The impact of the

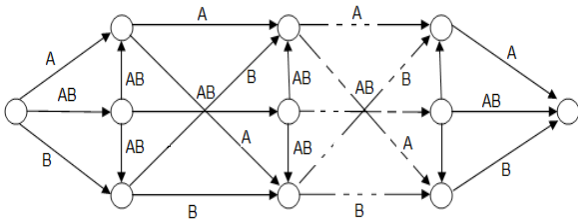


Figure 5. Transmitting packet in the proposed method.

Table 1. Simulation parameters

Parameter	The value of parameter
initial energy (Jules)	5 J
buffer size (packet)	1.000
Number of simulation rounds	5.000
Network size (meter)	200*200
Sink position (meter)	(200,200)
Number of nodes	50
Radio range (meter)	100
α	0.6
E _{elec}	50 nj/bit
E _{amp}	10 pj/bit/m ²
Data transmission rate	10 packet/s
Packet length	1000 bit
Buffer size	1000 packets

number of the produced packets and the initial energy of the nodes on the system efficiency in the proposed protocol and LIEMRO is illustrated in Figure 6. Figure 6(a) depicts the effect of the number of the produced packets on system efficiency and Figure 6(b) demonstrates the effect of the initial energy of the nodes on system efficiency in both the proposed protocol (IDRNC) and LIEMRO. As the figures show, it can be argued that the proposed protocol has better performance than LIEMRO.

As the number of the produced packets increases, the system efficiency in both protocols will decrease; That is to say, as the network traffic increases, the energy of the nodes decreases as a result of the heavy traffic and congestion. Consequently, the network life time will decrease, too. Thus, the system efficiency will be negatively affected. Although both the proposed method (IDRNC) and LIEMRO use the multi-path transition, the proposed method will have higher reliability since it makes use of the packet coding method.

5.1 Average Remaining Energy of the Network

The average remaining energy of the network is one of the parameters which indicate the network lifetime. The average remaining energies of both the proposed method

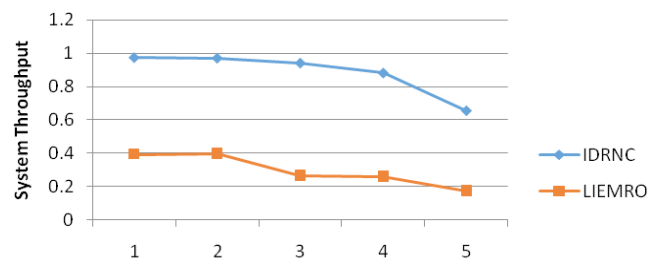


Figure 6. (a) The impact of the number of generated packets (packet/s) on system efficiency.

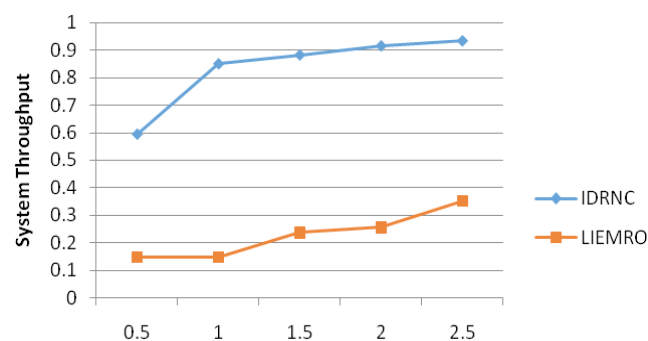


Figure 6. (b) The impact of initial energy (J) on system efficiency.

and LIEMRO have been demonstrated in Figure 7. As illustrated in this figure, the average remaining energy in the proposed method, with respect to the different changes of energy, is higher than that of LIEMRO. This result is due to the fact that the LIEMRO method uses controlling packets which consume significant amounts of energy. The higher the remaining energy of the network, the longer the network lifetime will be. Thus, the rate of delivering packets to the target and as a result, reliability will be enhanced.

5.2 The Number of Lost Packets

Reduction of the number of lost packets is one of the important parameters in determining reliability in the routing protocols. Figure 8 has depicted the impact of the number of lost packets in the proposed protocol and LIEMRO. As this figure shows, the number of lost packets in the proposed protocol with respect to the different variations in the data production rate is less than that of the LIEMRO method. As mentioned earlier in this paper, in the proposed protocol, the network energy is consumed more optimally than the LIEMRO method. Furthermore, due to the application of the network coding feature in the proposed method, the network traffic will be lower than that

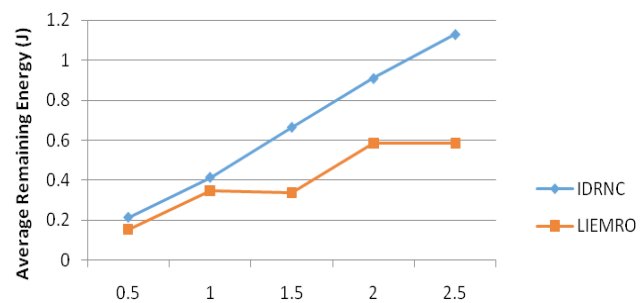


Figure 7. The impact of Initial Energy (J) on the average remaining energy of the network.

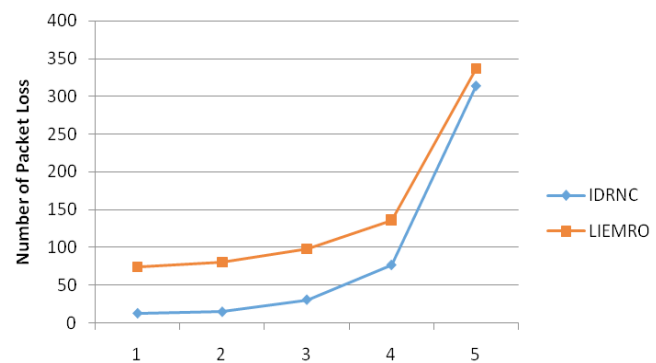


Figure 8. The impact of the number of generated packets (packet/s).

of the LIEMRO. That is, the higher traffic in the LIEMRO protocol is attributed to the utilization of the control packets and additional packets in the multi-path form which results in an increase in the number of lost packets.

5.3 The Average Length of the Line of Nodes

Traffic reduction in the entire network and load balance on the whole nodes is one of the remarkable parameters which enhance reliability in the network. The average buffered data in the line of nodes is one of the parameters for determine the traffic condition in the network. As depicted in Figure 9 below, the impact of the number of produced packets on the average length of the line of nodes in the proposed protocol is better than LEMRO. With respect to the fact that the proposed method uses the technique of network coding, the number of packets to be transmitted will be reduced due to the retransmission. As a result, the average length of the line of nodes in the proposed method is lower than that of LEMRO and the number of lost packets in the proposed method is lower which is attributed to the fact that the buffer is full.

6. Conclusion

Multimedia WSNs collect various types of textual and video data from the monitored environment and transmit to the sink. Reliability is one of the important parameters in these networks and enhancing reliability is a remarkable parameter in these networks. Using multipath transmission will enhance the reliability. Due to the broadcast feature of the wireless networks which use network coding technique, reliability, energy consumption and network lifetime will be enhanced in these networks.

In this paper, a multi-path routing protocol based on network coding was proposed for multimedia WSNs. In the proposed method, the parameters of remaining energy of the nodes and the number of hops were taken

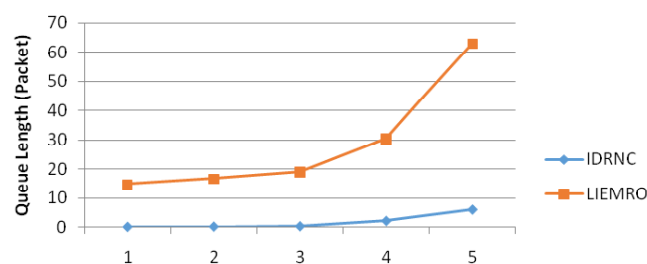


Figure 9. The impact of generated packets (packet/s) on the average length of nodes.

into consideration; then, the short paths from the source to the target were determined and the packets were transmitted to the sink through these routes. There were three paths and the middle path was the shortest one where the coded packet was transmitted through this packet. The simulation results indicated that the proposed method has optimized the parameters of successful transmission of the packets to the target and network lifetime better than the LIEMRO method.

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