Optimizing Throughput and Reliability by Piggybacking Retransmissions in Network Coding

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Abstract: In wireless networks due to the presence of unreliable links, efficiency and overall network performance degrades. To ensure the reliable end to end transmission, lost packets are retransmitted. Network coding improves the efficiency of network but susceptible to pollution attack in the presence of malicious nodes and links. The main concern of this paper is to limit the pollution attack by identifying malicious nodes and isolating it from the network so that the system can quickly recover from attackers Simulation shows that the proposed protocol OTRPR-NC routes the coded packets through the best possible path of the malicious network and minimizes the average no. of transmissions. It also optimizes the packet buffering, Network reliability and Retransmission time as compared to IPDR and ONCBT algorithms.

Keywords: Wireless networks; Optimization; Multicasting; Network coding; Encoding; Coding Gain.

1. INTRODUCTION

In wireless network information is broadcasted by means of commodity flow. Reliable communication[1] requires that transmitted information must be acknowledged by all the receivers properly but due to uncertainty of Wireless links, end to end packet delivery is achieved through packet retransmissions. In 2000 Ahlswede et al [2] introduced the concept of information flow to reveal that the throughput of a network can be enhanced over the routing capacity with Network coding. Earlier it was supposed that the transmission efficiency can be increased only by means of source and channel coding. But Network coding changed the scenario with the introduction of packet level coding. It allows nodes in the network to perform some algebraic or mathematical operations at intermediate level and routes the coded packet rather than simply transmitting a single packet at once.

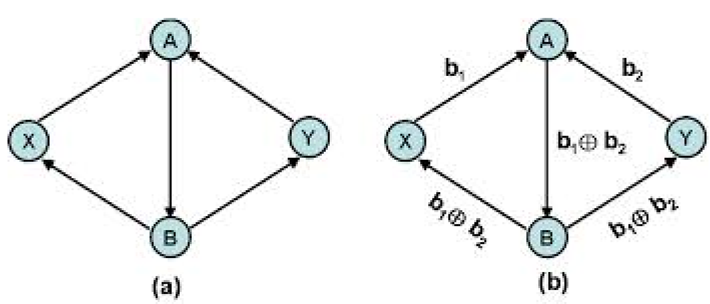

Figure 1: An Example of EX-OR Network Coding

As compared to traditional routing when Network coding is applied in multicast[3] scenario to the multi-hop networks, it reduces the energy utilization of nodes and resolves the congestion problem by routing innovative packets over alternative routing paths. It is best suitable when the network has extreme traffic loads and high transfer rate is required. Network coding also upgrades the throughput[4] and life time of the network[5] with the ideal utilization of network bandwidth. In this paper, on focusing the uncertainty of network links and hops, a real time retransmission scheme with EX-ORs Network Coding (as shown in figure. 1) is proposed to achieve the target.

Following is the summarization of our work:

i. Three factors (Malicious nodes, faulty links and link failure) are considered in the wireless Network. Proposed algorithm based on Piggybacking Retransmission NC for the retransmission of lost packet makes sure that each active node can recover the lost packet after every r time intervals. Further the packet to be retransmitted again, is clubbed with the another original packet of the route to optimize the transmission time.

ii. Influence of two factors (Packet loss probability of the link and injection of intruder node) on the average number of retransmissions is analyzed in Matlab. The results shows that OTRPR-NC minimizes the average number of retransmissions required and enhances the reliability of the network as compared to protocols in IPDR[14] and ONCBT[8].

Remaining Part of the paper is organized as follows. Literature Survey is presented in Section 2. Basic System model and various parameters used in the proposed Protocol are presented in Section 3. Detailed Methodology of the OTRPR-NC is stepped out in Section 4. Performance Analysis of OTRPR-NC is presented in Section 5 and the Section 6 gives the concluding remarks.

2. RELATED WORK

Concept of Network coding has been widely used for efficient data transmission in various networks. In delay sensitive networks broadcasting is an effective approach but it can lead packet collisions, redundant retransmission, and communication overhead. Many routing algorithms[6] are proposed in literature.

In [7] data transmission efficiency by XOR coding is depicted which has lesser complexity due to simple operations of XOR encoding/decoding. Protocol proposed in [8] prompts high transmission efficiency and lower transmission delay. Authors[9] provides methodology for improving the energy consumption by sensor nodes in Dual Homed Routing (DHR) algorithm and enhanced the vitality utilization & system execution in Wireless Sensor Networks within the sight of two Clusters. These Cluster Heads gathers the information and forwards to the base station. [10] depicted the transmission reliability issues in Informer Homed Routing (IHR) yet it prompts high communication overhead. Probabilistic Routing protocol based on Neighbor coverage (NCPR)[11] was intended for Mobile Adhoc Networks to reduce the steering overhead but the count of packet retransmission was increased which further leads to network congestion. Scalable broadcast algorithm (SBA)[12] was

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best suited for packet broadcasting and optimal route locating but was not energy efficient. Lu et al.[13] focused the broadcast networks with two special protocols ONCSB and ONCMB to improving the network throughput. In [14] the authors specially focused on reducing the packet loss probability and guaranteed the packet delivery at the node. However, all the above protocols are not suitable for complex calculations and could not prompt nodes sleep state. To overcome this problem a protocol ONRPR-NC is devised that can optimize the delay in transmission with low computational and communication cost.

3. MODEL OF NETWORK AND PARAMETERS

Here we are considering a Wireless Network with 100 nodes, single source, multiple sink nodes and multiple clusters. But for the analysis part only one sink and one cluster head is considered.
Let CH1 is the cluster head which broadcasts n number of packets P_1, P2,…, Pn to R. Where R= {R_1, R_2,….,R_m} are the sensor nodes. Each sensor node R_i produces a vector V_i which represents the active status of R_i. Where $V_i = \{b_i \mid b_i \in \{0, 1\}\}$. If R_i is inactive at any time slot t, b_i is 0 otherwise b_i is 1.

Definition 1 (Node active status AS): In Matrix AS each row represents the active state of receiver Ri and columns represent time slots t_i. Element V_{ij} in V represents whether R_i is active or not, at time slot j.

Definition 2 (Packet Receiving status RS): In this matrix, the receiving state of nodes is represented by rows and receiving state of packets by columns. When any node successfully receives broadcasted packets then the corresponding position a_{ij} in the matrix will be marked as 1 otherwise 0.

4. Proposed Methodology

OTRPR-NC algorithm adopts optimized route discovery and synchronous feedback mechanism for the reliable transmission of the packets throughout the network. Depending upon the feedback, the packet retransmission policy is decided in which retransmission of the coded packet or feedback (ACK/NCK) is embedded with the transmission of the original packets.

In this protocol prior to the packet delivery, integrity of the node is checked. If node has no intruder attack then only packet is transferred to that node otherwise that node is declared as faulty and isolated from the network to reduce the communication overhead. The transmitted packets are first encoded and moved towards destination through an optimal route. In case during transmission the packets are lost, then the intermediate nodes can identify and recover the missing packet through the coded packet. In this protocol faulty network links are also considered. If network link goes fail then also our algorithm continues its data delivery by adopting another optimal route based on M from recent node to the destination.

Steps of proposed Protocol are as follows:

1. Choice of an optimal adjoining node on the path.
2. Packet coding in present node.
3. Coded packet transmission.
4. Retransmission strategy for uncertain links

4.1 Choice of an optimal adjoining node on the path

OTRPR-NC algorithm starts with the discovery of optimal route for the packet transfer in the presence of faulty nodes and unreliable links in the network. In this protocol the complete routing path is not discovered at a stretch rather an optimal intermediate node of the path is decided. At the start source node finds out all its neighboring nodes which are at the distance of 2 units from it. It stores the location of all these nodes in matrix M. Now the distance of all these neighboring nodes from the sink is also calculated and stores in the matrix M.

Following equation is used to find the Euclidian distance between the two nodes a & b.

$$\text{Dist (a,b)} = \sqrt{(Xa - Xb)^2 + (Ya - Yb)^2}$$

Where (Xa,Ya) and (Xb,Yb) are the geographical coordinates of the nodes a and b .

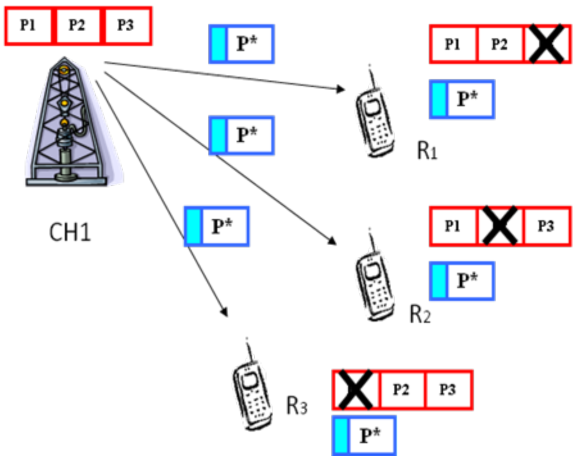
Format of matrix M is as follows

Coordinates of current node (Xa,Ya)	Neighboring node number #C	Distance of neighboring node from current node Dist(a,c)	Distance of neighboring node from Sink Dist(c,s)

A node with min (Dist(c,s)) is selected as optimal neighboring node. Before transmitting the data packet to the optimal neighboring node its integrity is checked by sending the encrypted code word. If the node is not malicious then only data packet along with encoded header is transferred to that node otherwise it is declared as a polluted one and it is isolated from the network to reduce the transmission efforts. Now next node with next min (Dist(c,s)) form Matrix M is selected.

4.2 Packet coding in present node

The proposed technique consists of data processing based on X-OR coding in which a coded packet contains the information of coding vector and the encoded data. Thus, when the receiver receives a coded packet, the recipient knows which packets are encoded mutually and how it can be decoded from the available packets at the receiver end.



Where

P*: An Encoded Packet and P*=P1+P2+P3

: A Header which tells the encoder how to encode a packet

X P*: A complete Packet containing Header and the Encoded packet

$$P^* = xP^T = [1\ 1\ 1][P1$$

x : Encoding Vector

P : Packet Vector

Fig 2: X-OR Coding of Network Coding

For the sake of simplicity we are focusing on single cluster (CH1) in figure 2 which depicts the coding method to the receivers R1, R2 and R3. At first time interval t1, CH1 broadcasts Packet P1 to all the receivers R1, R2 and R3. Similarly Packets P2 and P3 at time intervals t2 and t3 respectively. But after the delivery of all packets by CH1 the receiver R1 didn't get P3, R2 didn't get P2 and R3 didn't get packet P1. Now at time interval t4, CH1 broadcasts packet P* to all the receivers. Here P* is an encoded packet and each receiver can get the required packet from P*. R1 can recover P3 by calculating ((P1 XOR P2) XOR (P*)). Similarly R2 by performing ((P1 XOR P3) XOR (P*)) and R3 by ((P2 XOR P3) XOR (P*)). The result has been analyzed with the traditional method and it has been found that total 6 time intervals are required for the successful delivery of all P1, P2 and P3 to all the receivers and only 4 time intervals are required with coding to all R1, R2 and R3. Network coding combines different lost packets and reduces the number of retransmissions.

4.3 Coded packet transmission

After determining M, the optimal node transmits the coded packet to its neighbor node. Priority of a coded packet is always higher than the non coded packet. Although the priority of P1, P2 and P3 is same but all have the lower priority than P*. When any node receives a packet from its neighbor, it can verify what is required by it. Due to the presence of unreliable links it is not necessary that every active sensor receives the lost packet form the retransmission. So after ever T time slots it is checked that whether the lost packet can be recovered from the coded packet or not.

For this purpose each CH maintains Matrix RS which represents the packet receiving status of every node. Firstly, CH1 transmits an original packet. If the active sensor nodes receive the packet successfully, then they will send an ACK to CH1 otherwise NCK will be transmitted to CH1. After receiving ACK/NCK, CH1 updates its RS accordingly. Now after time interval T, a decision whether to execute detection mechanism is made. Next, a packet (coded/ original) will be transmitted. In that process, based on the matrices RS and AS lost packets should be selected. If packet recovery ratio

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(A) returns 1, a coded packet will be retransmitted otherwise the original packets should be retransmitted in the next timeslot, where

$$A = \frac{\text{No.of packets which can be decoded}}{\text{Number of active nodes}}$$

When A = 1; every active network node can recover a wanted packet. Otherwise, we will not execute retransmitting.

Matrix AS

	t1	t2	t3	t4	t5	t6
Sn1	X	0	x	X	0	x
Sn2	x	x	0	X	X	x
Sn3	x	x	0	X	0	x
Sn4	x	0	x	0	X	0
Sn5	x	0	0	X	X	0

Matrix RS

	P1	P2	P3	P4	P5	P6
Sn1	X	0	0	x	0	
Sn2	0	x	0	x	x	
Sn3	0	x	0	x	0	
Sn4	X	0	x	0	x	
Sn5	0	0	0	x	x	

4.4 Retransmission strategy for uncertain links

When the links are unreliable, the retransmission of the data packet is needed. Retransmitting packets after each time interval is very costly. Matrix RS depicts the retransmission requirement of any packet after T time intervals. In this method the retransmission of the coded packet is embedded with the transmission of original packets. Here ACK/NCK sent by the neighboring node to its sender after a fixed time interval (at) is further network coded. In this way the total transmission efforts are minimized and the average transmission time is improved.

Let *Sn1, Sn2, Sn3, Sn4* & *Sn5* are the sinks and t1, t2, t3, t4 & t5 are the time slots at different time intervals. At this point, CH1 has broadcasted five packets. Then, it needs to retransmit the lost packets in time slot t6. Matrix AS shows that all receivers are active at t1 time slot, only *Sn2* and *Sn3* are active at t2, *Sn1* and *Sn4* are active at t3, except *Sn4* all are active at t4 and at t5 receivers *Sn2*, *Sn4* and *Sn5* are active. At t6, *Sn4* and *Sn5* are inactive. From Matrix RS we can find that, Packet P1 is received at t1 by only *Sn1* and *Sn4* but *Sn2*, *Sn3* and *Sn5* have lost that packet. Similarly at t2, Packet P2 is only received by *Sn2* and *Sn3* and so on.

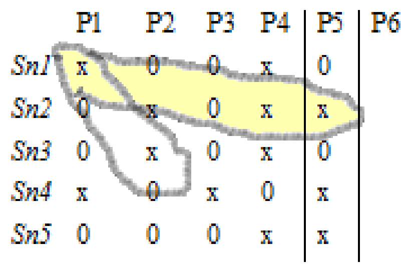

Fig 3 : Packet coding for retransmission of lost packets

Searching the matrix AS, we come to know that only *Sn1*, *Sn2* and *Sn3* can receive the lost packets at t6. So a coded packet P1 XOR P2 is transmitted at t6 in figure 3. From which all *Sn1*, *Sn2* and *Sn3* can get their required packets. If we suppose only *Sn1* and *Sn3* receives this coded packet at t6 and *Sn2* has again lost it then in the next time interval instead of broadcasting the same coded packet(P1 XOR P2), it will broadcast P1 XOR P5. So in this way *Sn1*, *Sn2* and *Sn3* gets all P1, P2 and P5 in just two time intervals. In next time interval, only P3 is broadcasted.

5. PERFORMANCE ANALYSIS OF OTRPR-NC

we simulate our proposed OTRPR-NC protocol in Matlab with following parameters.

Table 1: Analysis Parameters

Factor	Value
Network Size	225 * 225 meters
Sink Position	(210,200)
Network nodes	400
Packet loss probability l_i	0.3
Non active Nodes	0.05
Buffer size	1400 Pkts
Packet length	800 bits
Transmission Rate	12 ptks/sec
Simulation rounds	6

We analyze the impact of probability of the packet lost and selection of an optimal node on the coding gain of the network. Here the average number of transmissions required is considered as the simulation parameter. Let ω_a denotes the average number of transmissions with traditional retransmission approach and ω_b is the average number of transmission with OTRPR-NC.

$$\text{Coding Gain (C)} = \frac{\omega a - \omega b}{\omega a}$$

5.1 Network lifetime

Energy utilization by nodes is directly related with the lifetime of the network. During transmission

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some amount of energy is utilized in the communication path also. Proposed method OTRPR-NC is compared to the existing methods IPDR and ONCBT. The comparison result in figure 4 shows the OTRPR-NC is better than IPDR and ONCBT. At the initial stage, all protocols consumed almost the same energy but in successive time intervals OTRPR-NC utilizes less energy as compared to IPDR and ONCDS.

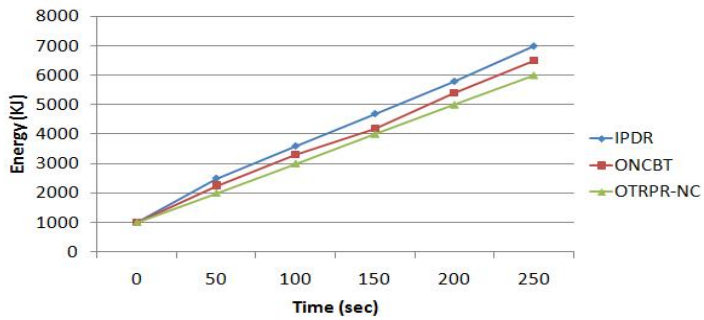

Figure 4: Energy Utilization

5.2 Packet Delivery Ratio (PDR)

PDR is the ratio of Number of successful packets received by the sink and the maximum packets transmitted. The network energy can be optimized and the traffic is reduced in the proposed technique by applying network coding. Reliability of transmission hikes up when lost packet are reduced. A huge number of packets are lost during routing in large networks but proposed algorithm persistently delivers packets to the sink and thus increases PDR depicted in figure 5.

$$\text{Packet Delivery Ratio(PDR)} = \frac{\text{No of packet received by sink}}{\text{No of packet delivered by source}}$$

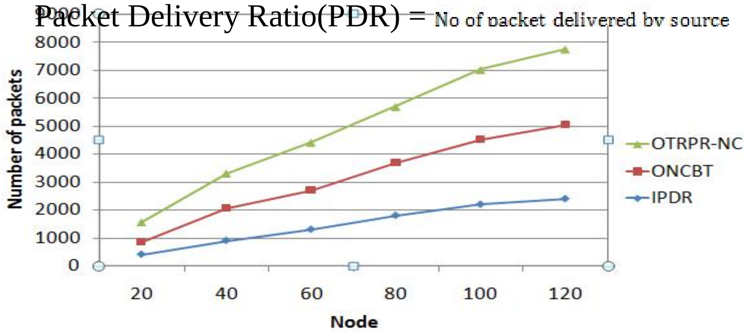

Figure 5: Packet Delivery Ratio

5.3 Buffering

Network reliability will be enhanced by reducing the traffic within network and also by balancing the load on whole network nodes. Congestion or traffic conditions within the network can be judged from the average no. of data packets already placed in the buffer. The number of disseminate nodes will be reduced using proposed method. Figure 6 depicts that queuing length of buffer for OTRPR-NC is lesser than IPDR and ONCBT.

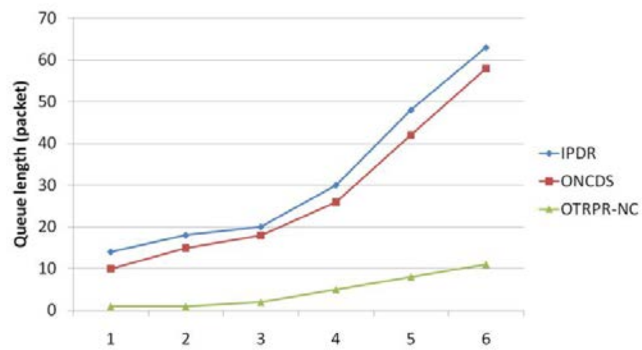

Figure 6: Queuing Length

5.4 Transmission Delay

During data transmission, packet delay occurs due to the routing overhead and search for the optimal path. Our proposed OTRPR-NC technique reduces the routing overhead as only 8 bit codeword is delivered for authenticity and it delivers the data efficiently with minimum delay to the destination shown in figure 7.

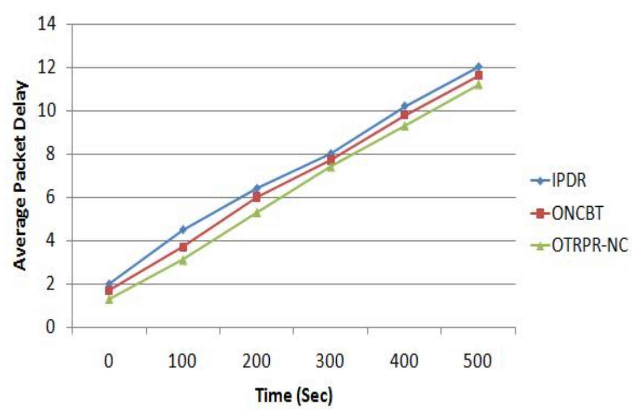

Figure 7: Transmission delay

5.5 Average Number of Transmissions

With the increase of network size, the total number of transmissions required are also increased. Here each batch contains multiple packets i.e. 15. The Packet Loss probability is represented by *li* and its value is 0.2 and the number of nodes in non active state is 0.05. OTRPR-NC requires least average number of transmissions and thus gives the better performance than IPDR and ONCBT techniques.

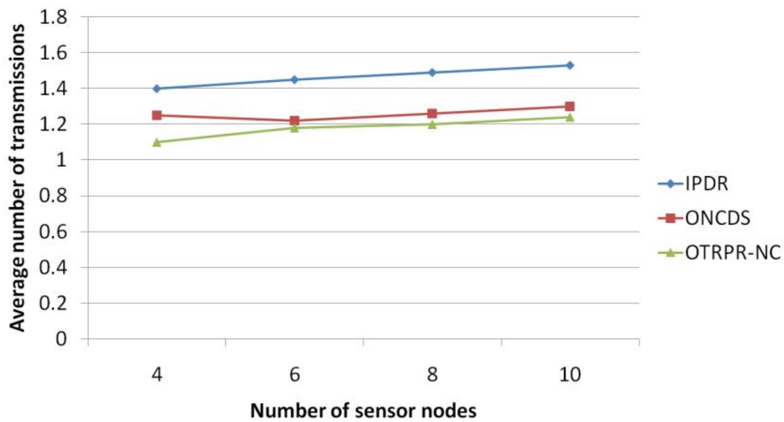

Fig 8: Average Transmissions Required

6. CONCLUSION

In this paper, the proposed OTRPR-NC protocol reduces the routing overhead by choosing optimal neighboring node and rebroadcasting probability. In this method the retransmission of the coded packet is embedded with the transmission of original packets. Moreover ACK/NCK is also network coded. We make sure that every active sensor through the value of A, can pick up the lost packet by retransmission method. So, that number of transmissions can be minimized and throughput can be optimized. The result shows that the proposed algorithm produces better results in terms of retransmission efficiency, packet drop ratio and average transmission time than IPDR and ONCBT.

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