Analyzing Network Coding in Loss wireless

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Abstract— Providing a reliable and efficient network services in wireless is very challenging mission because of the instability nature in wireless. For this reason, communication between devices using wireless could be lossy and lead to different issues such as noise interference losing packet and channel fading. Network coding has been shown to provide better throughput, more reliability and secure data transfer in various network topologies. In this research I study the reliability of broadcasting multicasting and unicast in lossy network using network coding in the packet level where the reliability defined by the probability that every node in the network receives the packets of every other node for broadcasting and subgroup of nodes for multicasting, whereas unicast is the case when there is one or more than one sender and one receiver. Also I covered some topics in wired network that has mutual impact with wireless network. Moreover, I present information on some security issues of a network coding system. I concluded my paper by discussing the future of network coding.

Key words: Network coding, unicast, multicast, broadcast, wireless

Introduction

In this paper I discuss the effect of network coding on throughput and reliability in different wireless topology. Network coding has been shown to offer exiting advantages in throughput, reliability and distributed operation for wired networks. These advantages have been translated into the wireless network setting and it has been proven its efficiency. Network coding improves throughput and provide elegant solution to congestion control and reliability, which considered as difficult traditional problem in lossy wireless. Broadcast, multicast and unicast are mechanisms for distributing identical information between nodes in network topologies. Unicast has the meaning that a packet is sent by one sender node to a specific receiver node (one-to-one). [21] However whenever there is more than one receiver then we moved to the other mechanism broadcast and multicast. Broadcasting refers to data transmission from one source to all the nodes in the network .Broadcasting could be used in many applications starting from satellite communications to wireless mobile ad hoc. Multicasting packet has some similarity with broadcasting but the only different is that packet is sent to some receivers nodes in the network instead of all the nodes in the network. [10]

Due to the fact that, network coding provides no advantages over routing especially for single unicast wired network which is not going to be covered in this paper. In this work concentrates in wireless where broadcasting and multicasting features in wired are similar to them in wireless. [12]

Errors, losing packets, interference and collision are main characteristics in lossy wireless network; this may lead to delay especially when data packets are transmitted by store-and-forward mechanism in traditional network. Network coding improves the transmission approach by allowing intermediate nodes to encode an outgoing packet by multiple incoming packets. [19]

This paper begins in the first section with an explanation of how network coding works and types of network coding .In the second section I go into more details about the reliability that network coding provide to lossy wireless network and conclude the work by discussing some issues related to the security.

Background and related work

Network coding is a promised field that has been studied by many scientists and specialists in the last 14 years. In this area of networking and data communication, coding have added a huge contribution to reach a better optimized solution in term of reliability like applying network coding on transfer control protocol TCP/IP [19] . Also network coding opened new doors to be used as solution for other computer science approaches like meeting distributed database requirements. **[13]** Furthermore, network coding has been used to reduce the needed power for multicasting using a set of sensors in Ashish and Sanjeev paper "On the network Coding Advantages for wireless Multicasting in Euclidean Space". **[1]** Inspired by all the previous works and researches I am writing this paper by investigation some of the advantages that has been discussed in one literature.

Lossy Network

In lossy networks, network coding provides robustness. Lossy network is the opposite of looseness network medium. We could use this term to call any net-

work where there is a room of losing packets or data while transmission happens between nodes. In wired network packets, collision is one of the feature that could a cause of losing packets. However, Wireless is another medium type, which could be considered as an example of a lossy network. Although, wireless network has great properties like proving great coverage with low cost and provides many arrangements, wireless medium includes many serious issues and challenges such as interference , race between devices to access the medium and packets collisions which all lead to a high chance of losing data packets. Also this considered as measure or scale to determine the performance of a network where the more property of losing packets is the lower performance this network provide.**[12]** For that reason in this literature my scope is to show some criteria that could be developed or modified and turn to give better performance and higher work quality.

Network coding

In the digital source approach, encoding is performed only at the source node whereas in a network all nodes achieving higher throughput could do coding encoding process. **[6]** Broadcast packet is special type of multicasting where in both types packet routing is an essential approach. In network coding the intermediate nodes are allowed to do the coding by mixing the incoming and the outgoing packets in specific way. So based on the previous information that are presented in the introduction, we could say that the main idea of network coding is to do the coding at each node individually and also to do the coding in every divided packet as well., and this coding is applied to the content of packets in order to incase the network throughput, reduce delays of received packets and make the network performance more robust and more efficient in term of reliability. **[19]**

Throughput in network coding is a term used to make the amount of communicating information more with fewer packet transmissions by using packet transmissions more efficiently. In the butterfly example, which is showing in figure1, we could show how network-coding affect in increases the throughput by these coming scenarios.

First scenario could be explained as if source nodes S1 and S2 want to send both packets p1 and p2 to receivers nodes or sinks D1 and D2, then D1 receives packet p1 from source node S1 and packet p2 from source node S2 in two times slots, and the same scenario will happen for sink or node D2 and this called a simple store and forward process. Second scenario could be explain with using network coding, where node D1 receives same p1 directly from the source node S1 and the same for the receiver node D2 with packet p2 in two times slots as total. But for the indirect links they receives packets p1+p2=p3 and the output will be called as p3 as one packet in one slot of time, then the receiver node D1 could inject packet p2 by XOR with the combine packet p3 since it is already has the packet p1 stored in its memory .Also for the receiver node D2 could inject the packet p1 by XOR it with the combined packet p3 for the same reason. This shows how network coding contribute positively on the throughput. These two scenarios could be apply in both wired and wireless networks.

Robustness is a phrase that is used for description a system that does not break down easily or a single application failure does not affect the whole system. However, robustness in network coding is linked with links failures and packet losses .Links failures, which keep primary and backup flow to be transited for each connecting to grantee a fast recovery from link failure. Packet losses could happen for several reason such as overflow, link outage, noise in the transferring medium (wireless medium) and collision. Erasure coding is one of the method that is used to provide a robustness against packets losses. Although erasure coding is special type of networks coding, it is different from network coding because the coding takes place in the source instead of the intermediate nodes. Security is another aspect on network coding that has both benefits and drawbacks. As an example for the security, benefits encoding the incoming packet and the outgoing packet offer a mechanism for secure communication. On the other hand, having a malicious node could be crucial where this node could prevent the decoding process on the other node because of the missing encoded packets.

Network Model

Nowadays most of the network structures is based on the assumption that information are represented separately as one unit but they share same resources, and this assumption is what most of network operations like routing , and error controls are built on. However, network coding does not follow this assumption, because of the combination process for input packets into one-output packets. Network coding could be represented in different model like the topology of network with a directed hypergraph use the term static subgraph for coding at each node. Also another example for network coding is the demonstration through the famous butterfly example as it shown in figure 1. **[19]**

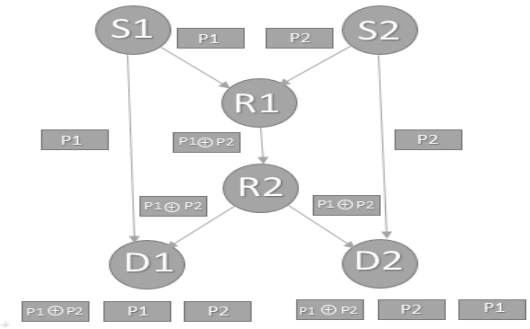


Figure 1: A simple scenario showing how network coding works by applying XOR on P1 and P2 in order to increase the throughput on the middle links.

In the model that shows in figure 1 we have 6 nodes {S1, S2, R1, R2, D1, D2} where S1 and S2 are the sender nodes and D1, D2 are the receiver nodes. R1 and R2 are the intermediate nodes, which send the combined packets come from S1 and S2 and send them as outgoing packets P1 and P2, which we could refer to it as P3. **[12]**

They show a comparison in coding and non-coding schemes for different topology like unicast and multicast network. They proved theoretically how using network coding increase the throughput using the butterfly example. Multicasting was one of the topologies they investigated by comparing four schemes. First scheme was without using Network coding but they include the interference factors. At this scheme, the throughput was the transmission rate on each link R divide by two. In the second scheme, the throughput was close to the first scheme taking on account not using coding and interference. Third and fourth schemes are different from first and second due to the fact that they use coding. In the third scheme, the throughput is 2R/3 with interference where the throughput for the fourth one was 2R/5 with neglecting the interference. **[13]**

How Network coding works

Since 2001 when R.Ahlswede, N,Cai,S.-Y.R.Li,and R. W.Yeung [1] introduced the basic idea of network coding in their paper "Network information flow" there are many literatures have proposed different algorithms that employ network coding over different scopes such as finding minimum cost multicasting or broadcasting using network coding which are related to solving the routing problem. My work focus on evaluating the benefits network coding may offer.

COPE is one of the first practical network coding that is used in wireless lossy network architecture. COPE algorithm uses information on overheard packets through transmission reports and combines multiple packets in one single transmission packet, which lead to an effective throughput. **[19]** Moreover, COPE in multi hops network structure that could use an efficient way to learn about other node information like which packets a node neighbors have by cooperation feature. Nodes do that by snooping where they exchange information between each other and save every node information. These information will be saved with all heard packets for a period of time in it is memory and that will assists the current nodes to make decision of decode packets when they received needed data. The fundamental idea of COPE is to benefits multiple nodes in one transmission which provide better throughput **[5]**

XOR, random linear network coding XOR Rescue (XORR) are examples of many network-coding algorithms where everyone aimed to solve specific problems and add many b advantages, but one of the disadvantages is that for this algorithm that coding and decoding schemas has to be agreed upon before head. Therefore, in the next section we shows some algorithms and what they added to what they are used for.

XOR Coding

Exchanging information between nodes in a wired or wireless network structure involves transferring both coded and encoding packets as well which is used to decode the coded packets. XOR is a logical operation of a type bitwise operation that is used to manipulate values the information exchange scenario happens between nodes. XOR process could be discussed from the packet prospective and the control flow prospective. path intersection as an example discusses XOR from the packet view, let's assume that we have three nodes S1, S2 and S3 as source which are not directly linked to each other t1, t2 and t3 are destination nodes where each node is linked to two source nodes and a common node that is getting contacted with all the node in the network topology. Each receiver node in the network will get two packets directly from sources nodes and one packet will be revived from the common node. This packet is a combination of all the three packets that has been sent from all the sources nodes. Based on this packets each receiver nodes could get the packet that has not been received directly from the source node which reflects the XOR approach in term of path intersection scenario. The control flow of XOR is presented by **[5]** as a way of making decision when a coding packet should be decoded in a nod or when it should be sent to a waiting queue or a memory in order to be forwarded to the next node. It is shown that after eliminating every received packets in a node by extracting all the reception report and acknowledgement, also inform the neighbors nodes about all the updated packets a checking process is being done. In case that packet target is the current node, it will be encoded first if it not in order to get the acknowledgement and inform the previous node about receiving packet. But if this packet is addressed to next node it will be sent to a queue in order to be send to another node as an output packet. Furthermore, when the receiver node is an intermediate node or in the middle between the sender nodes and the receiver nodes, it will initially encoded the packet first if it is not encoded yet, then it will be sent to it to its next destination nodes and repeat this process through all the nodes.

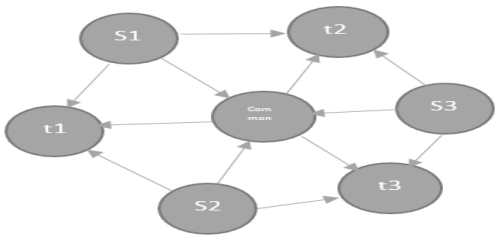
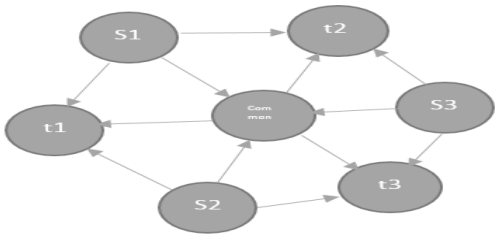


Figure 2: XOR coding [5]

Random linear network coding

M number of nodes could illustrate this scheme. We assume that we have k message packets w1, w2, w3, wk} which are in the source node and those messages are at first stored in the source nodes. The coding operations as we mentioned before will take place in every node, where each node first will receive packets and store them in the node memory then a random linear combination applied to the node contents to form the



injection packets as output packets. On the other side we have the sink node which collects the packets that sent by the source in order to decode them as final destination or assists in addressing them to the final destination.**[8]** they describe the details of implementing random linear network coding on openGL-enable Graphics Cards which is following the general idea of the random linear network coding concept which is build based on XOR scenario. In their work they applied their implementation on the CPU and the graphics card for their purposes However, their work was detailed enough to know more about network coding structure. OR and XOR are the used operations on the CPU. Furthermore, two arrays are used for multiplication and division. In the encoding process after receiving number of messages, it will multiply it by the size of the messages and save the result in a matrix of corresponding dimension taking in an account that bytes are shaped as a vectors Moreover, this operation is structured with an array lookups and XOR operation. The decoding mechanism takes place in the receiver node or the decoder. After the coded message are received, an elimination process is applied as a first step in decoding after storing the receiving data in a corresponding matrix. Then column and rows of decoding element match in specific way depending on the decoding matrix and ending with propagation until get all the data decoded. So as a summer of the main characteristics of linear network coding are the output of one node is found as linear that comes as a result of the input flows and it could be implemented in a low cost. **[17]**

Mesh network topology is well-known framework, which is a decentralized design that could play an important role in the internet in the future. This model is different from star topology that need a router to assist in delivering internet service. Mesh network nodes are connected to each other and they could talk to each other without requiring the assistant of routers. Intra-flow network coding and Inter-flow network coding are two general approaches for applying network coding to wireless mesh network coding which is showed when we discuss security and losing packets sections of this paper.

Unicast with network coding

Unicast is the process of sending a packet from one node as a source to other nodes as destination that could be refers to as one to one communication. In this way of communication, we covers some aspect that are related to the unicast due the similarity between it and the multicast and broadcasting.
As it known that most of network coding on wireless approaches studies the best path for a route or how can we can we retrieve a lost packets depending on the coded packets with cooperation with other packets. However, unicast with network coding could raise two issues, first one is the number of packets nodes should send and what is the content of these packets in order to show the gain of using network coding in unicast. **[21]**

[20] One of the literature analysis the unicast in wireless using network coding by a simulation that has been done based on the COPE approach to evaluate the performance of unicast network coding and the traditional unicast routing. The evaluation covered different schemes on a verity of network topologies such as shortest path routing with shortest path routing with network coding and other different algorithms. They found out that using network coding provide better performance than the traditional algorithms that do not use network coding.

Multicast structures with Network Coding

Multicasting a common used process nowadays in different types of applications such as teleconferencing, file sharing and video sharing. The different between unicast and multicast that it use one or more sources that send packets to more than one sinks nodes. [First paper in my folder]
Multicasting using network coding can be divided into routing where it determine the best path and the optimal rate to inject coded packet, and the coding to define the subjects of the packets. Before we go deeper and explore some issue related to multicasting with network coding we show the construction of multicast as a graph in a basic structure:

- Basic node that is consider as the main resource node.
- Intermediate nodes: they could be represented by all the nodes that are located in the middle between the source nodes and the receivers' nodes.
- Leave intermediate node: this phrase is for the entire node that are located at the end of the tree or we could considered them as the receivers' nodes or sinks.

More over all nodes that we have as receivers nodes or intermediate nodes are considered as children nodes where all the sender nodes cold be called as parents nodes. The graph below shows a basic structure for multicast where each node is connected with other nodes by line that is considered as paths or edges. **[4]** Also this structure could be referred as a tree structure where it has 4 levels starting from the parent node level and ending with the children node level in the bottom.

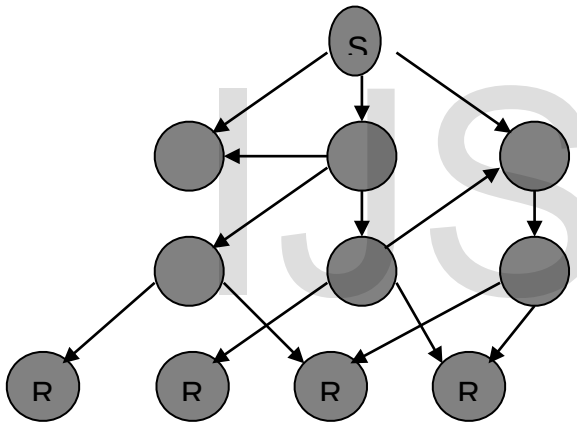


Figure 2. Multicasting network model – tree passed model [4]

One of the issues in multicasting is finding the shortest path from the source node S to one of the sinks. Giving that taking advantages of network coding in multicasting in wired network using Linear coding multicasting (LCM) they showed in their work that if there is one node with one input , a simple forwarding will applied. Otherwise, when there is a Node with two inputs these two input will be combine as one output using network coding. For instance, if we have an intermediate node that receives one input packet X from left and the second input packet Y from right. This intermediate node will compute C as combination of both inputs packets and send C out along all output links. According to their paper, they proposed a practical network-coding scheme for computing the minimum cost subgraphs for multicasting. **[4]**

Another aspect that has been studied in multicast is the performance where network-coding code assist in achieving better performance. Especially when it comes to the idea behind multicasting, which is having high capacity of data transmission. And this could lead to unstably issues even though using traditional method provide the same throughput as multicasting using network coding but it could save the network band-width by an effective traffic load balance. **[18]**

Broadcast structures with Network Coding

Broadcasting is a special type of multicasting structure where the main different between broadcasting a data and multicasting data is that multicast is a process of sending packets to subset of nodes in the network topology whereas broadcasting is a process of distributing or sending a packets to all the nodes in the network topology. Broadcasting in Radio communication network is one of the examples of broadcasting that has been studied in many researches and covered some problems like minimizing conflicts and increase the amount of information to more receivers.**[18][17].** Another approach for broadcasting with network coding is the efficiency of broadcasting to minimize the used energy. If we have any such classical communication model, we might have one source node and one destination node and a Chanel for transformation. Moreover, a source coding and a channel coding for handling errors. Nevertheless, in Broadcast structure we have one source node that want to send one unit of data to all receivers. Using network coding to this structure helps to decrease the number of transitions needed between nodes broadcast network packet to all the nodes in the network. Many algorithms has been introduced to approach this goal by analyzing different factors such as limiting the number of neighbors that receives each node broadcasting data to four neighbors or calculate the probability that a node S in the network is in the transmission range specific g number of times. However, a decentralized method has been suggested to be a solution for all these factors. **[2]**

Ad hoc network is a special kind of network that is used for transferring data between nodes with needs for a router to complete this process. Applying broadcast operation in this kind of network could cause many challenges getting all the nodes in the network busy every time a node want to broadcast one unit of data. Reducing the number of transmission approach has been studied and many algorithms have been proposed. A non-coding based localized algorithm called PDP was an efficient solution to achieve that with a cooperation with network coding. Two coding algorithms were used in this work an XOR **[5]** coding algorithm which allows decoding process in a node without a need to wait for more coded packets to arrive. Rad-Salmon –based is the second coding algorithm but it does not satisfy the case of not waiting to other coded packets **[3]**

Reliability

One of the main aspects that network coding provide is reliability. Due to the fact that transferring data in a lossy network where there is a lot of factors that effects on the reliability, Network coding added a lot of advantages and improvements such as throughput and data recovery and improve the reliability as well.**[14]** We introduced two works that have been done to analyze the reliability. **[10]** in this work they showed how they used XOR coding method **[5]** to or scheme to increase the reliability of recovering the lost packets for multiple common nodes. In the other literature **[15],** it has been showed how they investigate the reliability on of broadcasting data using network coding. A simulation was used to show how the algorithm that they introduce on their work achieved an optimal solution under the proposed coding scheme, also it provide bounds on the reliability of the network that they used to do their simulation.

Security in Network Coding

Mixing packets is one the special characteristics that identifies network coding. This process is a significant criteria takes place in the intermediate node before forwarding the mixed subjects. This process could have some advantages and disadvantages as well as we will discuss in this section.
Intra-flow Network Coding and Inter-flow Network Coding are two different approaches that could be used in different network topologies. However there is a small different of the ways they both work.
Intra-flow Network Coding used to mix data packets within individual flow whereas Inter-flow Network Coding does the packets into different flows.**[7]** In our work we will not investigate these two process in details but we will just introduce them to highlight the idea of mixing packets and how to they affect in some security issues in network coding. In our work, we will just introduce some popular topics related threats in network coding a brief summery or information without going in deep discussion.

Pollution attacks

Pollution attacks is one of the most famous threat and term that is used in wireless network coding. This attack happens when there is an attacker node propagates the corrupted packets into the network. The attacker node usually work as substitute to the intermediate node by injecting the corrupted node while doing the mix process. As a solution for this kind of threat checksum process is one of the suggested solutions, where every node could verifies the received packets. Although there is some cases where checksum process is not the efficient solution like if a node is isolated by many attackers from receiving the checksum , DART and EDART are two practical defense schemes which works efficiently with this kind of problem. **[9]**

"Secure Network coding for a wireless Mesh Networks: threats, Challenges, and directions" is one of the literatures that introduced different kind of threats and issues in network coding.**[7]** In this paper threats are divided into six main types of threats under two sub main types which are Intra-flow Network Coding and Inter-flow Network Coding.

Link quality falsification, Wormholes are examples of the first types under forwarding node section and rate assignments. Packets pollution and packet dropping comes under data forwarding threats, whereas acknowledgment threats could be represented by ACK injection, ACK dropping and ACK delay.

On the other hand, Inter-flow Network Coding introduces three potential security issues:

- Discovery of coding opportunities and it could be showed as packet reception information miss reporting, link State pollution or neighbor set pollution.
- Transmission of coded packets: it could be showed as ACK injection or modification, packet pollution, packet-over coding, packet under – decoding or packets dropping.**[11]**

Future of Network coding

As network coding become more popular in used in local networks, wide area network or even on much network topology which is became as the new coming structure for the internet. This implies that coding will have more turns in manipulating data. According to Frank Fitzek in his work "Network Coding for Future Communication and Storage Systems" that has been presented in Aalborg University, he has an expectation network coding is not going to be used as a way for transferring data and retrieving packets, but it might be the new technique of storing data in the network instead of storing it in solid storages. Also the flexibility of coding in network could lead to more cope to data and become more dynamic in term of mobility and storages.

Conclusion

This paper discussed and analyses network coding in different approaches. The discussion followed three criteria for analyzing network-coding approaches: throughput, reliability and a brief information about security. The concentration of this work was on the wireless network including three topologies unicast, multicast and broadcast. This paper also talked about Random linear coding algorithm and some details about COPE and XOR coding. This paper also labeled various issues related to mesh network, which is the

new used generation in the internet structure. At the end of this literature addressed to the future of network coding what some expectation for it.

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