The Network Coding based on Marked Packets

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ABSTRACT
In N–sinks and N-sources network, if the number of the received packets from the source is less than the number of the required packets to solve the linear independence relationship in the sink side, then the sink node will not be able to retrieve the event correctly. Therefore, in this paper, a new approach was designed to enhance the total number of meaningful packets (the true packets that describe the event without redundancy and malicious packets), throughput and availability in the network. The new approach was designed to enhance weighted and un-weighted network, taking into consideration two network types: wired and wireless networks. In the wireless networks, a simple approach was suggested to convert the wireless network to a graph problem. On another hand, a new reconstruction algorithm for the network topology was suggested by using extra information in the incoming packets. However, after analyzing the proposed algorithms and models, the proposed system achieved lower overhead, higher availability, lower traffic, and maximum lifetime.

General Terms
Security, Algorithms, Network, Coding, Marked packets

Keywords
Network coding; linear independence; network reconstruction; backup model.

1. INTRODUCTION
Using the network coding in the multicasting approach may improve the performance of the network such as: increasing the throughput, enhancing the availability and increasing the lifetime of the wireless nodes [1], if and only if the total number of received packets is less than the required number to solve the linear independence relationship in the sink side.

Moreover, improving the meaningful packets (the true packets that describe the event without redundancy and malicious packets) and reconstructing the network topology are discussed in many research papers as follows. Authors of [2] designed a new strategy for coding nodes to improve the encoding efficiency of wireless mesh network and system throughput. Where, a new model called Topology Awareness based on Network Coding with Feedback (TANCF) was proposed to reconstruct the network topology of the hierarchical P2P network based on the feedback from the intermediate nodes and the receiver nodes [3]. In addition, the complexity of network coding -finding minimum number of coded nodes- to maximize the throughput for specific environment was suggested and analyzed in [4]. Moreover, the trust protocol was combined with the network coding to minimize the influence of the bad nodes in the network and to increase the throughput of the network in [5]. Where, the problem of the dynamic network coding using the genetic algorithm was addressed in [6] to minimize the encoding nodes and to maximize the coding rate. On another hand, the new approach to control the redundant transmission was proposed; to study the performance of the loss that caused by the partial encoding and to protect from the malicious packet corruption [7]. Furthermore, many network coding routing models were proposed in the wireless network to improve throughput and reliability in wireless sensor network [8-10].

Encoding the packets in the intermediate nodes may enhance the network performance; increase the availability and the lifetime of the network. This enhancement is restricted on solving the linear independence relationship between the packets in the sink side. For example, consider the following motivating example shown in Figure.1. In this network, there are n sources (S) that multicast the data to n sinks (T) by using the intermediate nodes (i). Each intermediate node in the network either forwarding the packets, if the upstream is equal to one or encoding the incoming packets, if the upstream is greater than one, until the data is received by sink. When the sink (T) receives the packets in the coded and/or un-coded forms, the sink will try to solve the linear independence relationships between the incoming packets, so if the number of packets is less than the required number to solve the relationship then the sink can't retrieve the event otherwise the sink can retrieve the event correctly.

In Figure.1, the sink (T_L) can't retrieve the event correctly, since the total number of packets that received is not sufficient to solve the linear independence relationship between the incoming packets and some links and nodes send the same data to the sink node which will decrease the lifetime of the network and decrease the performance of the network. Therefore, to retrieve the event and to enhance the performance of the network in Figure.1, some links should be turned off and used as a backup links in the case of failure.

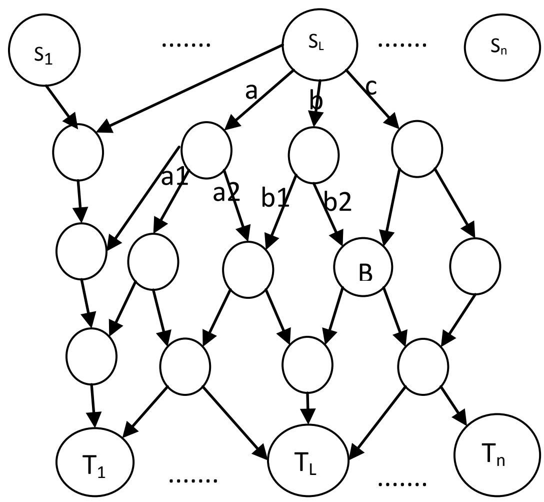

Figure.1: An example of the network coding.

Finally, our contributions in this paper are:

1. Increasing the total meaningful packets (the true packets that describe the event without redundancy and malicious packets) in the sink node by minimizing the number of redundant packets and unwanted coded packets.
2. Increasing the throughput, availability and the lifetime of the wired and wireless network.
3. Designing a network reconstruction topology for wired and wireless network.
4. Solving the single point of failure problem, if possible.

The rest of the paper is organized as follows: the proposed model is discussed in Section 2. Where, the backup system to improve the networks' nodes and the reconstruction system are discussed in Section 3. In Section 4, the discussion of the proposed system and algorithms are shown. Finally, the conclusions are drawn in Section 5.

2. PROPOSED MODEL

To simplify the problem analysis, the network will be converted to a graph problem, in which the communication of the un-weighted network is represented by a direct graph G= (V, E) and the communication of the weighted network is represented by a direct graph G= (V, E, W), where V is a set of nodes in G, E is a set of links and the W is the weight of transmission between two connected nodes in G. Moreover, to apply the proposed approach in the network, each intermediate node in the network should contain the information table that contains four columns, which are: link ID column, Status column to store the status of the link if it's turned off (0) or turned on (1), Up/Down column to describe the link position if it's upstream link or downstream link and Data column to store the link's data. However, each table will be modified depending on the notification message from the source. So, if one of the sending links becomes unavailable, the network will use backup links to increase the availability and the lifetime of the network.

In addition, each node in the network should send addition information depending on the following rules:

Rule.1: Each node that has one upstream and more than one downstream will mark each downstream packets (forwarded packets), for example in Figure.1 a will be forwarded into three nodes by giving each link own ID, like a1, a2, a3.

Rule.2: Each node that has one upstream and one downstream will forward the packet to the next node, where the counter for each packet will be incremented by one, for example a1 between layer 2 and 3, the packet will be forwarded and the counter will be incremented by one.

Rule.3: Each node that has more than one upstream and more than two downstream will be encoded and marked as rule.1,for example, the link a2 and b1 in node three layer 2 will be encoded and marked as (a2b1)1.

Rule.4: Each node that has more than one upstream and one downstream will be encoded and forwarded as rule.2.

2.1 Backup Model

The turned off links in the graph G will be used as a backup links in the case of failure, which will enhance and improve the availability of the network. In the weighted networks, the system will choose the next optimal backup links that minimize the cost of transition; to solve the failure problem. Where, in the un-weighted networks the system will choose any solution to solve the failure problem. Therefore, switching the case of nodes or links will effect on the network depending on the network types: un-weighted or weighted, and wired or wireless as will be discussed on details in the following subsections

2.1.1 Wired and Wireless Networks

In wired networks, the weight of the links between the neighbor's nodes is specified and each node will give each link a unique ID as shown in Figure.1. Where in wireless networks, the data will be spread in a circular form and all the nodes within the communication range will receive the data. Therefore, a simple approach is used, to convert the wireless network to the graph that contains vertices and edges. The approach will divide the communication range of each node depending on the number of neighbor's nodes and their positions which will allow each part to see only one neighbor.

In Figure.2 three cases are shown, to divide the communication range of wireless node into a set of regions depending on the neighbor wireless nodes properties (position and number). In Figure.2 (b-c), the nodes are divided into three parts, where in Figure.2.a the communication range is divided into two parts, each one of these parts is given a unique ID such as 1, 2, etc. However, there are many ways to apply this division, and there are infinite solutions to split the communication range, so any solution of these solutions that gives each neighbor a unique ID will be considered. Finally, after dividing each node, the graph will be created depending on the incoming information that sent from the intermediate nodes.

2.1.2 Un- weighted and Weighted Networks

The meaningful information can be increased in the sink node, if some links in the network are turned off. Turning off the links may turn off the nodes that didn't have any upstream links or downstream links. So, to increase the meaningful packets, the best path for each packet needs to be defined. In the un-weighted network, there is no best path, since any path that increases the meaningful packet will be chosen. Where, in the weighted network the best path for each packet will be chosen. For example, to find a solution of the network in Figure.1 (assume the network is un-weighted network). First, pick any solution by turning off the maximum number of links (backup links) in the graph G, which is equal to the total number of links that increased the availability of the network without decreasing the total number of meaningful packets. So, in the case of failure any links could be used to solve the problem and the turned off links may be used in the future to enhance the network throughput. Where, in the weighted network, the optimal solution will be chosen, since the minimum value for the path is chosen.

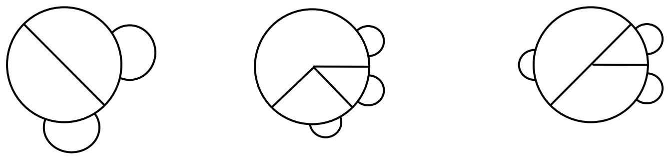

Figure.2: Dividing the communication range of the wireless nodes, to convert the wireless network into a

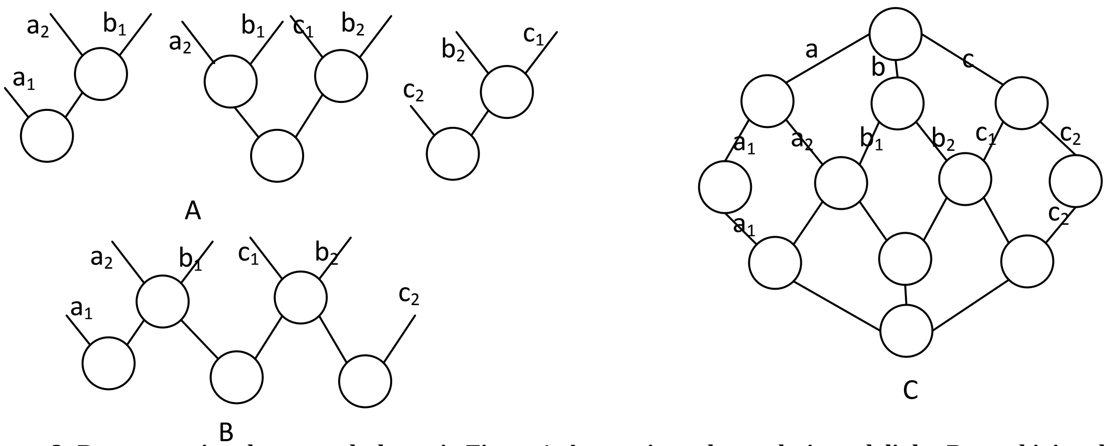

Figure.3: Reconstructing the network shown in Figure.1. A: creating sub-graphs in each links, B: combining the sub-graphs from the step.1 and C: Creating the forwarding nodes for the same data, combining the same packets and

Lemma.1: in the un-weighted network G= (V, E), if the total number of links in G is greater than the total number of links that's needed, to send the packets to the sink node directly. Then the system can generate n solutions to enhance the network but can't find the optimal maximum turned off links.

After turning off the maximum links in the network and stopping the coded nodes, the network's performance will be enhanced.

Lemma.2: in the weighted network G= (V, E, W), if the total number of links in G is greater than the total number of links that's needed to send the packets to the sink directly, then the system could find the optimal maximum turned off links.

In the weighted network, the system tries to find the optimal solution that represents a path for each packet from the source to the sink, to achieve minimum weighted value in that path. The solution will be ordered depending on the optimality, so in the case of failure, the system will pick the next optimal to increase the availability and the performance of the network.

2.2 Reconstruction Model

The meaningful information in the sink side can be increased, if the useless and redundant links are turned off and used as a backup link in the case of failure. In this section, two algorithms are discussed, to improve the weighted and un-weighted networks, algorithm.1 and algorithm 2, respectively. Where, algorithm.3 discussed the reconstruction model for the network topology in the sink side.

Algorithm.1 starts by finding the packet that has minimum number in the sink side (x-packet) and choose one of the received links (x-link) as a solution to the x-packet, where the rest of possible packets will be stored in the stack with its link ID. All the links that send x-packet through x-link will be turned on, where other nodes that send x-packet through other links will be turned off. In addition, in algorithm.1 the backtracking is used to find any possible solution that enhances the network, since there is no optimal solution can be defined for un-weighted network. However, if all paths are validated and no solution is found, the algorithm will return no solution.

Algorithm.1: Network enhancement for un-weighted network

```
Sol= { a,b,c….} // the unique packets from the source
unique_solution[Sol.ID] // number of links for unique packets.
info_table [ ]
Find_path(Node node)
{
min =get_min(node.unique_solution)   //1
link_ID=link_min(min)
Links.add(link_ID,min)
Put possible solutions in separated nodes in the stack within it's current status
Remove(min,node.Sol)
Update node.unique_solution
Turnoff other links in link_ID using info_table
Turnoff the redundant min packets in other links //8
if all the links checked
    if any solution found
        return Links
    else
        clear Links
else
        if stack is non_empty
                pop the node off the stack
                Find_path(node)//recursive function
        else   return No solution
}
```

The enhancement model for weighted network is shown in algorithm.2. The first 8 lines for the two algorithms are the same. In algorithm.2, the system will try to find all possible solutions by using the backtracking method and take the optimal solution that has minimum weighted value, where in the first algorithm the first solution found will be returned.

Algorithm.2: Network enhancement for weighted network

```
Sol= { a,b,c….} // the unique packets from the source
unique_solution[Sol.num]
info_table [ ]
Find_path(Node node)
{//the same code in algorithm.1 from line 1-8
if there is any solution found
 Flag=1;
     if  optimal_weight <  current_weight
        Clear Links
        Pop node from the stack
        Find_path(node)
     else
        optimal_weight = current_weight
        store the optimal path
else
        if stack is non_empty
            pop the node off the stack
            Find_path(node)
       else
            if(Flag==0)
                  return No solution
            else    return optimal Links  }
```

Algorithm.3 is used to reconstruct the topology of the network by using rules in section 2, which takes the information in the incoming packets to reconstruct the network topology. The first step is to create a sub-graph for each link, then combine the sub-graphs together and reduce the redundant links to create one huge graph that describes all the nodes in the network. Finally, depending on the number of the forwarding packets and the number of layers in the network, the forwarding nodes will be added to the graph, to complete the graph of the network.

Algorithm.3: Network reconstruction topology

Create a node for each packet in each link
for each LINKS
Create a sub-graph from different links
end for
Combine the sub-graph from different links
Create forwarding nodes depending on the forwarding number in each packet and the number of layers
Create nodes to combine the same packets
Create upper layer nodes from the source and lower layer node from the sink

3. EXAMPLE

In this section, an example to enhance the network throughput and to solve the single point of failure by using the backup nodes will be discussed. By considering the network in Figure.1, (assume that the network is un-weighted) and after applying algorithm.1. The sink TL will receive the following packets depending on the received links (table.2 row 1):

Link1 = $a_1\ (a_2 b_1)_1$
Link2 = $(a_2\ b_1)_2\ (c_1\ b_2)_1$
Link3 = $(b_2\ c_1)_2\ c_2$

The first step in algorithm.1 is to extract the unique packets from the received packets as follows (table.2 row 3): a, b, c. Then, choose one direct link for each packet such as: a1, b1 and c2 from link 1, 2, and 3 respectively (table.2 row 4), where the nodes that have zero upstream will be turned off like node B in Figure.1. However, the turned off links will be used as backup links/nodes in case of failure; to enhance the network characteristics.

Table.2: One of the suggested solutions to enhance the network in Figure.1

Variables	$Link_1$	$Link_2$	$Link_3$
Incoming packets	$a_1\ (a_2b_1)_1$	$(a_2\ b_1)_2\ (c_1\ b_2)_1$	$(c_1\ b_2)_2\ c_2$
Unique Solutions (US)	a, b	a, b, c	b, c
US for all links	a, b, c		
Chosen packets	a_1	b_1	c_2
Turned off (backup)	$(a_2b_1)_1$	$(b_2\ c_1)_2$, c_1, a_2	$(c_1\ b_2)_2$, b_2
Turned off nodes	Node B in Figure.1		

4. SIMULATION EXPERIMENT AND DISCUSSION

The evaluation simulation is written in visual C++.net. The simulation used the network in Figure.1, after adding more nodes in the level 4. In the evaluation tests, four parameters are used: the total number of meaningful packets received in the sink, the lifetime of the network, the total number of packets transmitted between the source and the sink through the intermediate nodes and the consumed energy in the network. Where, the simulation parameters are: the simulation time 30 seconds, number of nodes 30 nodes, 3 sources, 3 sinks, TP: the time needs to create a relationship between the source and the sink (TL) as shown in Figure.1; TP is equal to 4 seconds in following tests.

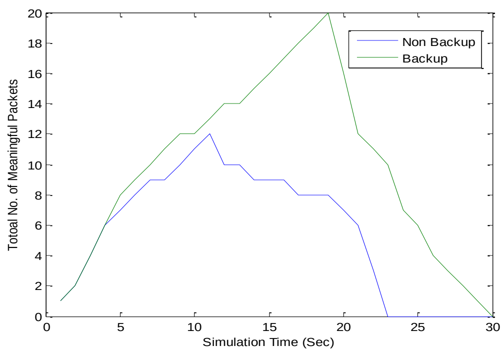

Figure.4: Total number of meaningful packets

4.1 Network availability

The total number of meaningful packets in our proposed model is better than the non-backup model as shown in the Figure.4, since the network will only use the nodes that find the optimal weight in the case of weighted network or any solution in the case of un-weighted networks. In the two cases, the turned off links in the network will be used as a backup links in the case of failure, which will maximize the availability of the network. Hence, increasing the availability of the network will increase the information about expected event by turning off some nodes and using them as a backup nodes/links in the case of failure, which will increase the total number of the meaningful packets in the sink side.

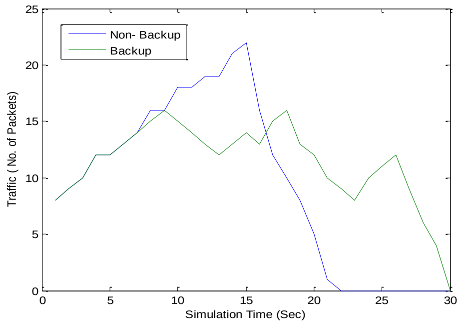

Figure.5: Total number of packets in the network.

4.2 Traffic on the network

The total number of traffic in the backup model will be minimized as shown in Figure.5. Since, some nodes/links will be turned off and will be used as a backup nodes/links, which will decrease the transmitted packets in the intermediate nodes and increase the useful packets that describe the event.

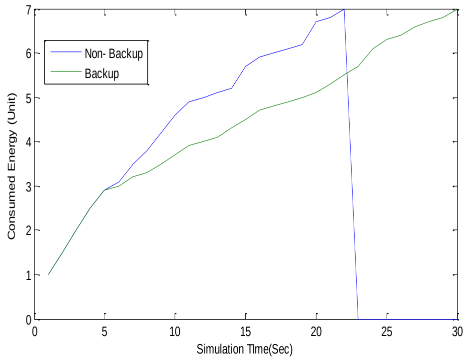

Figure.6: The total energy consumption in the network.

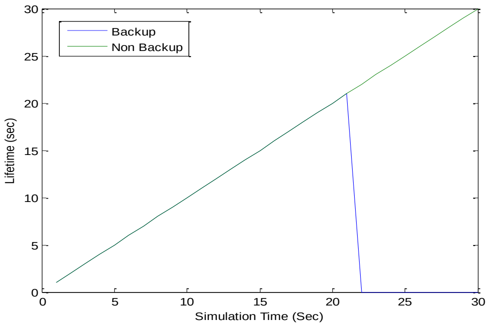

Figure.7: The lifetime of the network.

4.3 Network Lifetime for the Wireless Nodes

The lifetime of the network is depending on two variables: the energy consumption and the effectiveness of the backup links in the network. Therefore, after enhancing the network, the number of transmitted packets that processed and forwarded in the intermediate nodes will be minimized, which decrease the energy consumption in the overall network as shown in Figure.6 and increase the lifetime of the network as shown in Figure.7. On another hand, the backup model will increase the lifetime of the network, since the backup links will be used in different time units.

5. CONCLUSION

In this paper, a new enhancement and reconstruction approaches for the coding nodes in different network types and models were designed. In enhancement approach, the system will increase the total meaningful packets in the sink side. Where, in the reconstruction approach, the system will rebuild the network topology in the sink side using the information in the incoming packets. In the first stage of our analysis, the weighted and un-weighted networks were discussed and analyzed, where in the second stage the wired and the wireless networks were discussed and analyzed. The proposed system analysis shows that the proposed models will achieve higher availability, lower traffic, and will minimize the total energy consumption in the wired network. Where, in the wireless networks the lifetime will be maximized. On another hand, the overall throughput per time unit is improved because all the information will describe part of the original data. However, discussion show that the proposed system can be used in different network types and models, such as un-weighted networks, weighted network, wired and wireless network.

6. REFERENCES

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