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Research paper

Network Coding aware Routing for Efficient Communication in Mobile Ad-hoc Networks

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Abstract

Existing approach of routing protocols had only partial support towards energy efficiency. However, none of them had focused on considering network coding aware routing to reduce energy consumption. Majority of the existing solutions in literature to improve the communication performance of MANET has focused on minimum cost routing protocols. There are very less significant studies towards network coding in performing routing in MANET system. Therefore, it is totally unknown how network coding could be used to solve such issues. Throughput in wireless networks can be enhanced with the help of network coding. This approach also increases network lifetime in the cases of devices running on battery, such as wireless sensor nodes. Additionally, network coding achieves a reduction in the number of transmissions needed for transmission of a specific message through the network by making energy usage more efficient. Despite its benefits, however, network coding can have a negative impact on network lifetime if it is implemented excessively. •Initially, to achieve the goal of improving throughput, reducing energy efficiency by reducing the number of broadcasting transmissions, a network coding model is created in this study and the MANET broadcast based on network coding is improved by the heuristic principle of Ant Colony Optimization. This study proposes the application of a network coding based dominating set approach to traditional routing protocols like adhoc on demand distance vector (AODV) as a solution to this issue.

Coding gain of different topologies with different offer loads is evaluated using network coding. We discussed performance of Alice-bob, cross, X, and wheel topologies using network coding. The study has paid particular attention to the trade-off between selection of paths compatible with network coding and network lifetime. The present study addresses this compromise that demonstrates that networks with energy restrictions are incompatible with the current network coding strategies based on throughput. One routing issue is attributed particular importance, namely, reduction of overall energy usage and improvement of individual node lifetime through effective routing of a series of traffic demands over the network .A range of analytical formulations are put forth to generate an optimal solution for the issue of multi-path routing. Results show that, by comparison to solutions without network coding, the suggested solutions improve energy efficiency while at the same time satisfying the specified lifetime restrictions.

Keywords: *Wireless ad hoc networks; Routing; Network coding; Energy Minimization.*

1. Introduction

A wireless computer network without a fixed infrastructure is known as a wireless ad-hoc network. MANETs are one of the kinds of wireless ad hoc network with large applications in the recent scenario. MANETs consist of a peer-to-peer, self-forming, self-healing network. From last decade the major research area which had a large contribution in wireless networking is Mobile adhoc network. Till date research is being carried out on problems like routing issues [1] [2], energy issues [2], security issues [3], load balancing issues [4], congestion control issues [5], etc in mobile adhoc network. Out of all the problems much attention is attained in routing and security. Few research works e.g. [6 - 8] supports implementation of energy efficient routing in mobile adhoc networks.

A mobile node will be either in an active state, in sleep state, or in a passive state [9]. It dissipates energy in any state. Due to the energy retention scheme in the nodes, broken links [10] risk exists, which is highly detrimental to the communication principle.

For more than two decades, much research work has been done on problems towards efficient use of bandwidth, energy efficiency and improving throughput in mobile ad hoc network.Till date, there is no efficient solution for energy efficiency for over burdened resource constraints nodes [11]. Most of the research was carried on routing [12-13], conservation of energy [14], security [15], congestion control and load balancing [16].The main problem is routing schema [17] is not considered in the traditional routing protocols . A closer look at the trends of research reveal that majority of the studies were towards routing. But it's observed that less number of works was being carried out in designing network coding aware routing [18] in the mobile ad-hoc network. The evolution of network coding aware routing[22-25] is not new, but they are more involved in the theoretical study and less in practical implementation. However, usage of network coding is not that much clear in the research area of the mobile ad-hoc network.

This had leaded the network coding based systems to improve their throughput and reduce their energy consumption as well. Therefore, this necessitated a need to develop a network coding aware routing in mobile ad hoc network which can address life time, throughput, energy efficiency and bandwidth issues. Further, such routing protocols can significantly reduce the load of routing and multiple operations that are carried out by mobile nodes in a MANET. Finally, it can decrease the number of transmissions, minimize energy consumption, improve throughput and enhance network life time

Based on the above survey of research works carried out on MANET routing the following are the research challenges in network coding aware routing protocols.

- To develop network coding aware routing in mobile ad hoc networks to reduce energy consumption.
- To increase the communication performance of MANETs using above routing protocols.
- To improve throughput and life time using coding aware routing protocols.

Therefore, the problem statement of the research work under investigation is “design and implementation of a network coding aware routing protocols” that can be used to improve the communication performance between mobile nodes in a MANET. The next section describes our contributions to solve the above said problems.

2. Research Contributions

The above problem is proposed to explore with three different phases and the corresponding solutions are proposed in the following sub sections. Phase I addresses the minimum cost routing problem in a MANET. It is solved by developing a network coding aware frame work for a MANET to apply it in an AODV routing protocol. The outcome is measured as the network coding gain and throughput. The performance of Alice-bob, cross and wheel topologies with network coding that was developed in phase1 is studied and evaluated with different loads in phase II to determine coding gain. The phase III addresses the energy depletion problem by developing energy efficient path using earlier developed network coding in a MANET. The outcome of this phase is efficiently minimizing energy and enhancing network life time. All the three contributions are described are described in the following sub sections from 2.1 to 2.3.

2.1. Network coding-aware AODV routing in MANETs

We aim to design[21] and implement a network coding-aware routing protocol in order to improve the communication in MANETs. For this purpose a proposal is made at the subsection 2.1.1.The implementation of the proposal is explained at the subsection 2.1.2.The experiments on this implementation are described at subsection 2.1.3.The results obtained in those experiments are analyzed at subsection 2.1.4.

2.1. 1. Proposed system

This subsection presents a proposal on the network coding aware routing protocol. For this purpose a network coding flow model is also proposed at fig.1. Network coding consists of four major modules namely listening, learning, coding and decoding. These modules are described below.

Listening: In network coding, the packets which could be employed at a later time to decode the coded packets must be listened to and stored by the nodes. These packets can be derived from two main sources, Packets transmitted by the nodes themselves and packets overheard by nodes. In general, packets are directed to just one next hop and the overheard packets not intended for them are disregarded by the nodes.

Learning: The learning module is in charge of monitoring the packets stored by a node’s neighbours in their listening module. The monitoring procedure can be based on deterministic information on packets .The availability of packets is to be in one of two ways .First, confirmed by the sending of reception reports by the neighbouring node .Second, by the fact that the nodes were previous hops on the route taken by the packet. Nodes must have knowledge about the packets that their neighbours have in their packet pools in order to be able to undertake network coding.

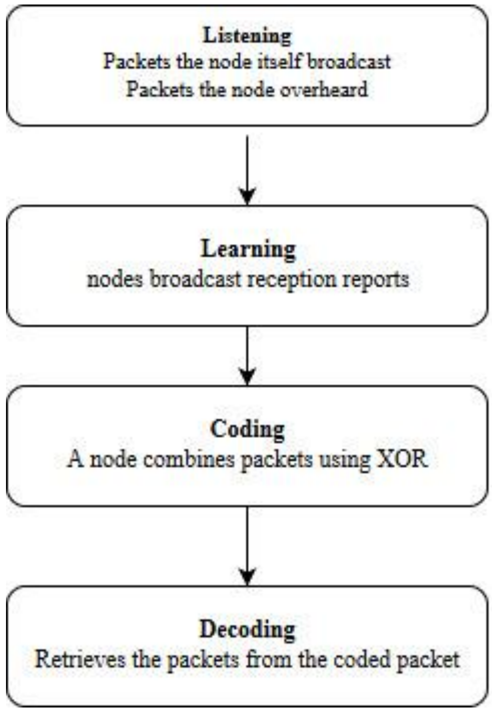

Fig. 1: Flow Diagram of Network Coding Model.

Coding: The coding module is used to code the packets at the nodes in the network. These packets are available in a queue at every node. They are forwarded for broadcast to the next hop as they arrived i.e., in FIFO. Every node in network gets an alert for an opportunity of packet transmission. In this opportunity, the first packet in queue is coded with other packets in the queue. For this purpose, the packets are combined .the combinations of packets are chosen based on an Ant Colony optimization. Combining packets and broadcasting the new packet to the neighbor nodes depends on several attributes of ant colony optimization.

To achieve packet combination, the pheromone values must be calculated as follows:

$$PH(n,\{p1,p2,\ldots.pk\}) = \sum^{k}_{i=1} P(x_i) / (\text{code length} - 1) \quad (1)$$

$P(x_i) = N(x_i) \cap NE(\{p1, p2\ldots pk\})$ for each k = 2 onwards.

The pheromone value must be code length -1 to be taken into account. Total Pheromone Value = $\sum^{k}_{i=1} P(x_i) / (\text{code length} - 1)$

Were $N(x_i)$ = Packet of node x_i

$NE(f_i)$ = no.of encoded packets associated with forwarding nodes

$P(x_i)$ = node x_i pheromone value.

Code Length = number of packets xor’ed together.

Based on the above description a network coding algorithm is proposed as here under.

Algorithm 1: Network coding algorithm

1) The packet set k {p1, p2, p3,…pk} is selected from the output buffer ;
2) Determine the forwarders of network and select the packet combination from 2 to k, for every combination, formula (1) is used to determine and update the pheromone value;
3) Repeat the previous two steps and update the pheromone table;
4) Upon finalization of an established number of trails, the optimal combination is chosen;

The network coding algorithm, first selects the packets at the relay node from the output buffer to combine them. It next finds all the possible combinations from 2 to k and periodically calculate the pheromone values for each combination by using equation

1. Then it updates the pheromone values as in the table 1. Finally, it selects the combination of packets with maximum pheromone value, which is an optimal combination. The network coding algorithm is explained with an example.

Consider a network with 6 nodes as given at fig.2.This fig.2 shows an example MANET with nodes A, X1 to X5.Node A is a relay node.X1 to X5 are its neighbor nodes. The packets available in these nodes are displayed underneath respective node. For example, node A has p1 to P7 packets in it. Node X1 has P2, P3 and P5 packets in it. Similarly all other nodes from X2 to X5 are also displaying the availability of packets in themselves. Packet information is loaded onto the five neighbors {x1, x2, x3, x4, x5} of node A. The assessment of the network code is undertaken by node A for its buffered packets {P1, P2, P3, P4, P5, P6, P7}. The pheromone table 1 is updated with the values obtained with formula given at equation1 for each combination, assign out of packets starting from 2 to 7.

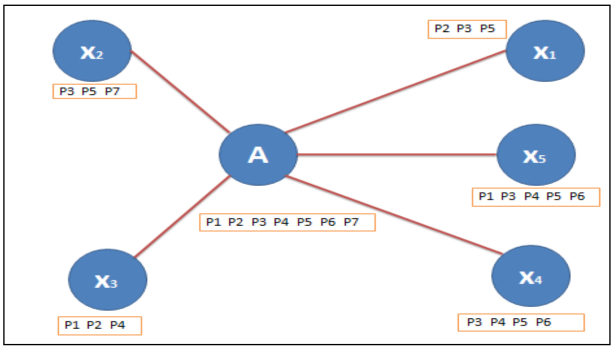

Fig. 2: Network Comprising Node A with Five Neighbour Nodes {X1, X2, X3, X4, X5}.

Table 1: Pheromone Values

Nodes / Number Of Encoded Packet	X1 Pheromone value of X1	X2 Pheromone value of X2	X3 Pheromone value of X3	X4 Pheromone value of X4	X5 Pheromon e value of X5	Total Pheromone value
P1+P2	1	0	0	0	1	2
P1+P2+P3	2	0	2	0	2	3
P1+P2+P3+P4	0	0	3	0	3	2
P1+P2+P3+P4+P5	0	0	0	0	4	1
P1+P2+P3+P4+P5+P6	0	0	0	0	5	1
P1+P2+P3+P4+P5+P6+P7	0	0	0	0	0	0

Table 1 holds the data related to the nodes and their corresponding pheromone values. Column 1 represents all the possible packet combinations. Column 2 to 6 represents pheromone values for nodes X1 to X5 respectively. Column 7 represents the total pheromone value for each packet combination. From the above table it is observed that, packet combination P1+P2+P3 has maximum pheromone value. This combination of packets can retrieve maximum number of native packets when compared to other combination of packets.

Decoding: A node receives encoded packets .These packets must be decoded at the node. First, it checks all the IDs of the encoded packets. Then, it extracts n-1 packets from the listening node after an XOR with received encoded packets. Next, the native packet meant for that node is extracted. If n-1 packets are not available at the node, then the encoded packets are discarded.

Further, this research work is carried out on connected dominating sets (CDS) based Aodv routing protocol. It proposes an application of and dominating pruning (DP) approach to current routing strategy adhoc ondemand distance vector (AODV).

Algorithm 2: Network coding aware CDS based AODV

1) Creation of a MANET with non-specific number of nodes.
2) Initialize the packet information at nodes.
3) Apply the dominant pruning algorithm for finding the connected dominating set. Initialize the set as forwarder set.
4) Apply the ACO algorithm to find the optimal combination of packets at each forwarder node.
5) Broadcast the packet combination through CDS nodes.

The network coding aware CDS based AODV algorithm first creates a network topology for specified number of nodes. Where in each node contains a queue for packets. Using neighbour knowledge it selects a few forward nodes to produce a connected dominating set (CDS).On this CDS a heuristic Ant Colony Optimization is applied at each forwarder node to optimize packet combination. Finally, broadcast this packet combination through the CDS nodes.

The implementation detail of this proposal is described in the next subsection.

2.1.2. Implementation

The implementation of proposal described in the previous sub sections is done using Network Simulator-2(NS-2) [22]. NS-2 is an object oriented simulator. It is a discreet event simulator which provides substantial support for the simulation of routing protocols, such as AODV, DSR etc. It provides us the facility to create a new protocol by modifying or by adding new functions in the existing routing protocols.

The following are the methods that are used from the existing AODV protocol available in NS-2.

1) Void sendHello ( ) function is used for sending the Hello messages.
2) Void sendRequest ( ) function is used to send Request messages.
3) AODV::recvAODV (Packet *p) function is used to differentiate the incoming AODV packets.

If the incoming packet is of type RREQ: recvRequest (p) is called, RREP: recvReply (p) is called, RERR: recvError (p) is called, HELLO: recvHello (p) is called.

Further, these are the new methods that are added to the existing AODV routing protocol for network coding.

1) AODV::recvencoded (Packet *p) is developed in c++ to receive encoded packet. It receives the encoded packet and checks weather it is the destination and calls the decode function to decode else it forwards the same to its next neighbor.
2) AODV::encode () function performs network coding using ant colony optimization to maximize coding gain. It retrieves the packet combinations from function copy_packet(). Finds the optimal packet combination using Ant_colony () method and assigns new id for the selected packet combination.
3) The AODV::decode (Packet *p) function is developed to get native packets from the encoded packets. To execute decoding process, it will check its local packet pool to retrieve n-1 packets and perform xor coding to retrieve native packet. The packet pool stores the retrieved packet.
4) AODV::copy_packet (Packet *p) function is developed to combine packets together. Each packet is appended with the other packet to create an encoded packet. It also copies all the parameters like source id, destination id, sequence number, next hop of a packet into the encoded packet and prepares a new packet.

The experiments conducted on this implementation is described in the next subsection.

2.1.3. Experiments

This sub section describes experiments conducted on the implementation. All the experiments are conducted on a desktop computer loaded with Linux operating system and NS-2.The simulation is conducted on NS-2 with the simulation parameters as listed at table 2

The experiment begins with deploying nodes in the simulator using node deployment model. Traffic is sent to destinations using traffic model with the help of Constant Bit Rate (CBR). The number of nodes are changed for every simulation which ranges from 10 to 50 with an increment of 5 nodes for every simulation. The pause time, network size and duration of simulation are fixed at 30s. The network field size is 500m X 500m. For each point 10 random scenarios are generated by 10 simulation runs for each protocol. Average of these is used to plot the graph by changing the number of nodes. Trace files are generated after each simulation when the respective TCL files are executed. These files are analyzed to calculate the throughput. The results in these experiments are furnished in the next subsection.

Table 2: Simulation Parameters

Parameter	Value	Description
Number of nodes	40 -160	No of nodes in simulation
field range x	500m and 2000	x-dimension
field range y	500m and 2000	y-dimension
power range	250m	power range of node
Mac protocol	IEEE 802.11	MAC layer protocol
Network Protocol	AODV	Network Layer
Node placement	Random	Nodes are placed in random
simulation time	15m	according to simulation clock
mobility interval	10-30sec	Nodes pausetime
Propoagation function	FREE space	propagation function
Transport layer protocol	UDP	Transport layer

The results obtained in this experimentation is described in the next subsection.

2.1.4. Results & analysis

The results obtained from the above simulations and their analysis is presented in this sub section. The parameters used to analyze the results are throughput, end-to-end delay, route requests.

Throughput: The rate at which a node can send the data through a network. It is calculated as follows:

Throughput=Received_packet_size*8 / Simulation time (kbps)

The simulation results in trace files comprising all the parameters listed at table2.

The comparison for the existing AODV and AODV using Network Coding (AODV-NC) is presented at Fig.3 using throughput. The graphical outcome shows that AODV with NC offers more throughput when compared to the existing protocol AODV. Main reason for this is, in AODV using Network Coding more than one packets are sent in single transmission, which in turn reduces the number of transmissions and increases the throughput.

End-to-end delay is the time taken for a message to reach the destination from the source. The following are the components used to calculate the end-to-end propagation time (PT), transmission time (TT), queuing time (QT) and processing delay (PD). Therefore, EED is evaluated as:

$$EED = PT + TT + QT + PD.$$

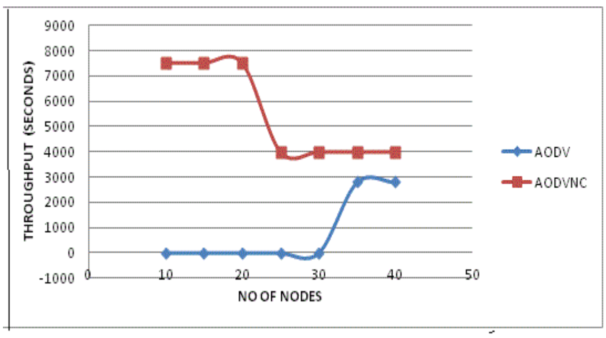

Fig. 3: Comparison of Throughput.

The fig. 4 plots a graph of AODV vs AODV using network coding to analyze the end to end delay. The graphical outcome shows that AODV with network coding has less delay when compared to the existing AODV protocol. Main reason for this is in AODV using network coding the concept of connected dominating set with network coding is used which decreases the end to end delay between the nodes compared to the traditional AODV protocol.

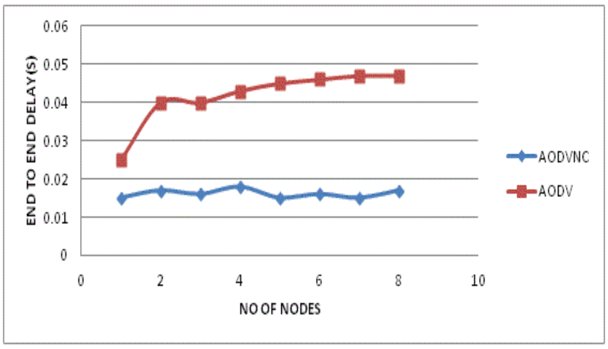

Fig. 4: End-To-End Delay Measured in Seconds.

Route Request (RREQ): When a node aims to send a packet to its destination, first it checks its routing table to confirm whether it already has a route to the destination. If the answer is yes, it forwards the packet to next hop. If the answer is No, it starts route discovery process for establishing a route. The process of Route discovery starts with the creation of a Route Request (RREQ) packet.

The fig.5 plots a graph of AODV Vs AODV using network coding to analyze the number of route requests. The graphical outcome shows that AODV with network coding need less number of route requests when compared to the traditional AODV protocol. Main reason for this is In AODV using NC only dominating set nodes are responsible to forward the route requests.

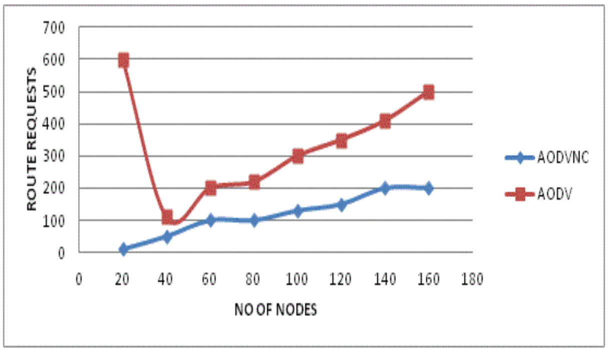

Fig. 5: Comparative Examination of Route Request.

Network coding aware AODV routing mechanism doesn't possess much hold on the topologies based performance with network coding to address the problem of communication in Mobile ad hoc networks. Therefore, various topologies are considered to evaluate performance of network coding aware model. It is presented in next sub section.

2.2. Network coding-based communication in various topologies

In this work, we evaluate the coding gain obtained in different topologies with different offered loads in alice-bob, cross and wheel topology using network coding .For this purpose a proposal is made at the subsection 2.2.1.The implementation of the proposal is explained at the subsection 2.2.2. The experiments on this implementation are described at subsection 2.2.3.The results obtained in those experiments are analyzed at subsection 2.2.4.

2.2.1. Proposed system

The basic idea of alice-bob is explained in fig.6. Here, node1 need to send packet A to node 3 via node 2.Similarily node 3 need to send packet B to node 1, via node2. This transmission is done by using 4 transmissions (1->2, 2->3, 3->2, 2->1).The same can be reduced to 3 transmission (1->2, 3->2, 2->1, 3) using network coding shown at fig.7. The intermediate node encodes the packets by performing xor operation and transmits the encoded packet in single transmission to nodes 1 and 3.Therefore the packet transfer is done in 3 transmissions instead of 4 transmissions.

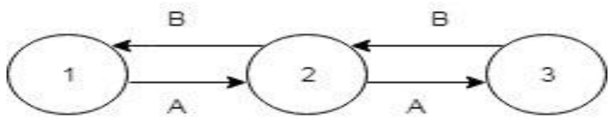

Fig. 6: Alice-Bob-Topolgy with Traditional Approach.

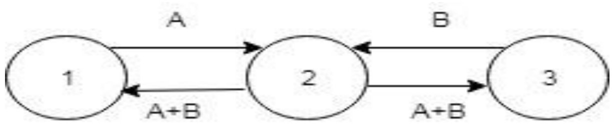

Fig. 7: Alice-Bob-Topology with Network Coding.

Fig.8. is an example of cross topology which includes the concept of overhearing. In this topology 4 nodes A, B, C, D need to deliver packets to their respective opposite nodes. When node A transmits packet P1, node B and C overhears it. Similarly when B transmits a packet P2, A and D overhears it. The same goes for other 2 nodes. When non coding approach is used to deliver the packets total 8 transmissions (A->X,X->D,B->X,X->C,C->X,X->B,D-.X,X->A) are required.When network coding is applied at node X only 5 transmissions(A->X.B->X,C->X,D->X,X->A,B,C,D) are required to send the packets to the destinations as shown at fig.9

Now we consider another example by increasing the number of nodes in the network. fig.10 shows wheel topology where many flows are interesting at the center. Consider a situation where 4 nodes deliver packets to apposite nodes via a relay node. This requires total 8 transmissions when traditional approach is used. If network coding is applied to the relay node, the number of transmissions are reduced to 4.Therefore coding gain of 8/4 is obtained.

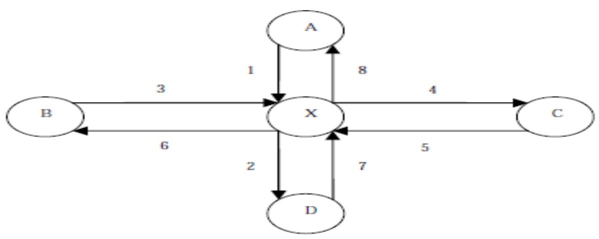

Fig. 8: Cross-Topology Using Traditional Approach

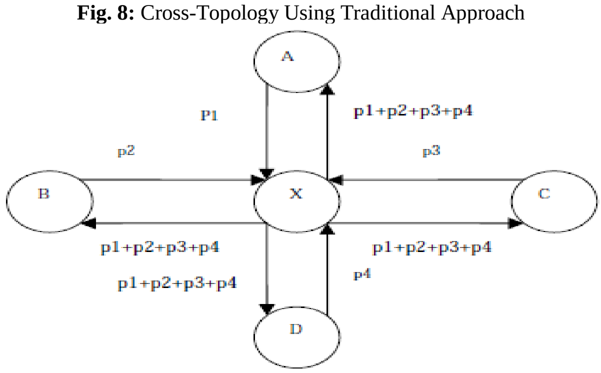

Fig. 9: Cross-Topology Using Network Coding.

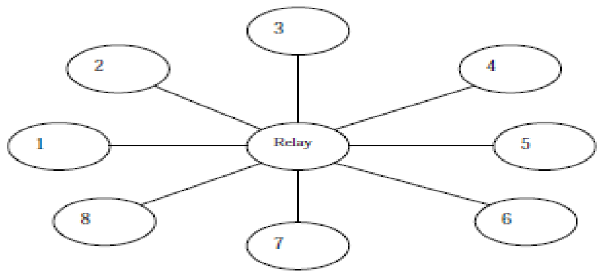

Fig. 10: Wheel Topology.

In this proposal above topologies are considered to implement the algorithms proposed at subsection 2.1.1.The implementation details are explained in the next subsection.

2.2.2. Implementation

The proposal described in the previous sub sections is implemented using NS-2[20]. The alice-bob, cross and wheel topologies are used for this implementation. First Random Tool () is used to create alice-bob topology. Next To, send the packets from source to destination, network coding based AODV protocol is used proposed at 2.1.1.

The following are some of the functions that are used from the existing AODV routing protocol in NS-2 as cited at subsection 2.1.2.However, they are furnished here under for ready reference.

1) Void sendHello ( ) method is used for sending the Hello messages.
2) Void sendRequest ( ): This method is used to send Request messages.
3) Recv(Packet *p): This function classify the incoming packets type.
4) RecvRequest (Packet *p): This function is invoked when a node receives a packet of type REQUEST.
5) RecvReply (Packet *p) this function is invoked when a node gets a packet of type REPLY.

The following are the new functions that are added to the existing AODV protocol for performing network coding as cited at subsection 2.1.2.However, they are furnished here under for ready reference.

1) Encode () function performs network coding using ant colony optimization to maximize coding gain.
2) Recvencoded (Packet *p) receives encoded packet for routing the packets to next node.
3) Copy_packet (Packet *p, const Packet *pkt) is used to combine the packets.
4) Decode (Packet *p) is used to decode packets.

Next the implementation is carried out in the same way for cross and wheel topologies.

2.2.3. Experiments

This sub section describes experiments conducted on the implementation. All the experiments are conducted on a desktop computer loaded with Linux operating system and NS-2.The simulation is conducted on network simulator-2 with the simulation parameters as listed at table 2

The experiment begins with deploying nodes in the simulator to create alice-bob topology. The network field size is 500m X 500m. Rand function in Tool Command Language (TCL) script is used for topology creation. Offered load is increased at the nodes with the help of CBR. Simulation duration is fixed at 30s. The number of nodes are changed for every simulation which ranges from 10 to 50 with an increment of 5 nodes for every simulation. The pause time, network size and duration of simulation are fixed at 30s. The network field size is 500m X 500m. For each point 10 random scenarios are generated by 10 simulation runs for each protocol. Average of these is used to plot the graph by changing the number of nodes. Trace files are generated after each simulation when the respective TCL files are executed. These files are analyzed to calculate the throughput. The same procedure is continued for cross and wheel topologies. The results in these experiments are furnished in the next subsection.

2.2.4. Results & analysis

The results obtained from the above simulations and their analysis is presented in this sub section. The parameters used to analyze the results are throughput and offered load. The fig. 11 plots a graph of Alice-Bob topology with network coding and without network coding to analyze the throughput with different offer loads. The graphical outcome shows that alice-bob with network coding offers more throughput when compared to alice-bob without network coding. Main reason for this is when network coding is applied on the relay node, two packets are encoded together for single transmission and therefore offers more throughput.

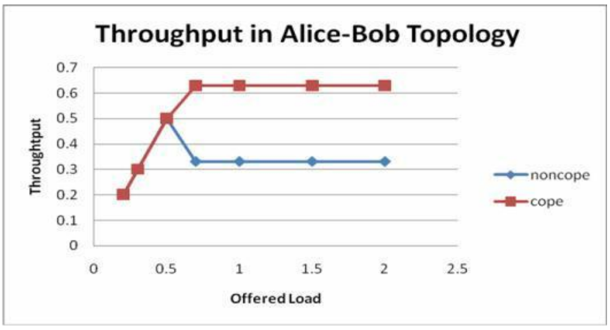

Fig. 11: Throughput in Alice Bob Topology.

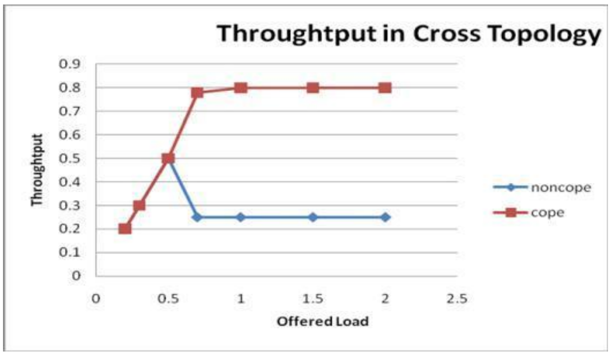

Fig. 12: Throughput in Cross-Topology.

The fig. 12 plots a graph of cross topology with network coding and without network coding to analyze the throughput with different offer loads. The graphical outcome shows that cross topology with NC offers more throughput when compared to cross without NC. Main reason for this is, when the network coding is applied to the system, node x can code 4 packets together and therefore the system throughput peaks at 4/5.when the offered load is increased further the throughput remains at the saturation level of 4/5.

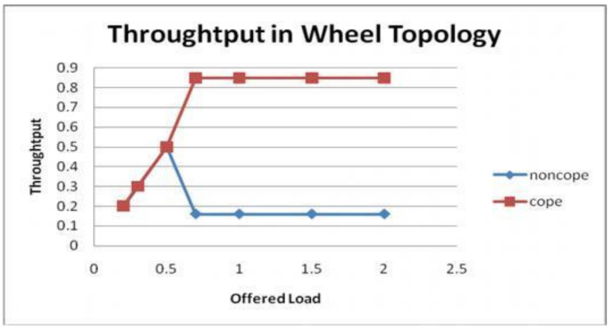

Fig. 13: Throughput in Wheel Topology.

The fig. 13 plots a graph of wheel topology with network coding and without network coding to analyze the throughput with different offer loads. The graphical outcome shows that wheel topology with network coding offers more throughput when compared to wheel without network coding. Main reason for this is, when the network coding is applied at the relay node, 6 packets are combined together and thus throughput peaks at 6/5.

The above two approaches are targeting the performance improvement in network coding aware routing. First approach uses the dominant set nodes to improve the network coding gain. Whereas, the second approach uses relay nodes for coding and improves the network coding gain. In these two approaches the energy of dominating nodes as well as relay nodes is observed to drain out quickly. This leads to network disconnection or loss of network. Therefore in order to minimize the energy consumption at each node and increase the life time of the network another proposal is made. This new proposal is discussed in the next section.

2.3. Network coding-aware routing for energy minimization

The present study addresses the improvement of individual lifetime of nodes and reduction of overall energy consumption of the network. For this purpose a proposal is made at the subsection 2.3.1.The implementation of the proposal is explained at the subsection 2.3.2.The experiments on this implementation are described at subsection 2.3.3.The results obtained in those experiments are analyzed at subsection 2.3.4.

2.3.1. Proposed system

This subsection presents a new proposal for minimizing the energy consumption of nodes and increasing the life time of the network. For this purpose an algorithm for Energy Minimization with Lifetime Constraint (EMCL) is proposed. Pseudocode is furnished as here under.

Algorithm for Energy Minimization with Lifetime Constraint(EMCL)

1) Assign initial energy to each node (0 to 100).
2) Find multiple routes for a given source to destination
3) In each path If BS<20 then Wn=Wn+1
4) Select the route with minimum number of Wn.
5) If two paths have same number of Wn, calculate TBE(total battery energy) of these paths.
6) Select the path with maximum TBE.

The above algorithm performs as follows:

The EMCL algorithm first creates a network topology for non-specific number of nodes. Where in each node is assigned initial energy (0-100J). A node with Battery Status (BS) <20 is termed as weak node. Multiple routes are discovered for the network by using network coding based Ad hoc on-demand Multi path distance vector routing protocol (AOMDV). Next calculate the number of weak nodes in each path. A path with less number of weak nodes is selected. If more than one path has same number of weak nodes, calculate TBE of these paths. TBE is the sum of battery status of all the nodes in the path. Select the route with maximum TBE.

The implementation details of this proposal are described in the next subsection.

2.3.2. Implementation

The implementation of the above algorithm is done using NS-2. First TCL Scripts are used to create a network with random number of nodes. Then Network coding based AOMDV routing protocol is used to discover multiple paths from source to destination. The following are some of the functions that are used from the existing AODMV routing protocol in NS-2.

1) AOMDV::sendRequest(nsaddr_t dst) This function is used to start the route discovery process.
2) AOMDV::recvRequest(Packet *p) This function is called when a node receives a packet of type request.
3) AOMDV::sendReply(nsaddr_t ipdst)This function is called when a node receives a packet of type reply.
4) AOMDV::recvAOMDV(Packet *p) This function is called when a route is discovered from source to destination.

The following are the new functions that are added to the existing AODMV protocol for performing network coding as cited at sub-section 2.1.2.However, they are furnished here under for ready reference.

1) Encode () function performs network coding using ant colony optimization to maximize coding gain.
2) Recvencoded (Packet *p) receives encoded packet for routing the packets to next node.
3) Copy_packet (Packet *p, const Packet *pkt) is used to combine the packets.
4) Decode (Packet *p) is used to decode packets.

Next energy model of NS-2 is used to simulate energy in network coding based AOMDV

The following are some of the functions that are used from the existing energy module in NS-2.

DecrTxEnergy (), DecrRcvEnergy(). Structures are used to hold initial energy of each node.

1) start_powersaving (): This method is used to shift the node to power saving mode.
2) DecrTxEnergy (txtime, P_tx)): This method decreases the energy level of the node when it transmits a packet.
3) DecrRcvEnergy (rcvtime, P_rcv): This method decreases the energy level of the node when it receives a packet.

The experiment conducted on this implementation is described in the next subsection.

2.3.3. Experiments

This sub section describes experiments conducted on the implementation. All the experiments are conducted on a desktop computer loaded with Linux operating system and NS-2.The simulation is conducted on NS-2 with the simulation parameters as listed at table 2. The network field size is 500m X 500m. Initially a network with random number of nodes is created using TCL scripts. Energy is assigned for the nodes using energy model. Traffic is generated from source to the destination with different traffic loads and different channel capacities, with the help of constant bit rate. Simulation is run for 30s.In simulation, 10 random scenarios are generated by 10 simulation runs, for each sample point of a particular protocol and the average value is used to plot the performance of a network by varying the number of nodes. Trace files are generated after each simulation. These files analyzed to calculate throughput.

The result obtained in this experimentation is described in the next subsection.

2.3.4. Results & analysis

The results obtained from the above simulations and their analysis is presented in this sub section. The parameters used to analyze the results are energy consumption, channel capacity, traffic, lifetime and remaining energy

- Energy Consumption is computed as $E_c = E_c\text{-}(E_t + E_r)$.

Ec is energy consumption of node. Et is the transmit energy consumption. Er is the receiving energy consumption.

- Channel Capacity is defined as the maximum data that can be send from source to destination over a communication channel

The fig.14 plots a graph of EMC (Energy Minimization with Coding) Vs EMCL to analyze the energy consumption with different channel capacities. The graphical outcome shows that EMC and EMCL offer less energy consumption when compared to the routing protocol without network coding. Main reason for this is in EMC more than one packets are sent in single transmission, which in turn reduces the number of transmissions and reduces the energy consumption. In EMCL as the life time issue is considered the energy consumption slightly more when compared to EMC.

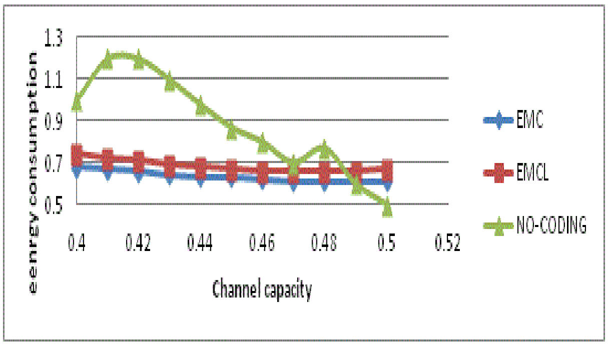

Fig. 14: The Impact of Channel Capacity on Energy Usage.

Traffic: Network traffic or data traffic is the amount of data moving across a network at a given point of time.

The fig.15 plots a graph of EMC vs EMCL to analyze the energy consumption with different traffic factors. The graphical outcome shows that EMC and EMCL offer less energy consumption when compared to the traditional protocol. Main reason for this is, as the traffic increases at the nodes, coding possibilities increases and therefore energy consumption decreases.

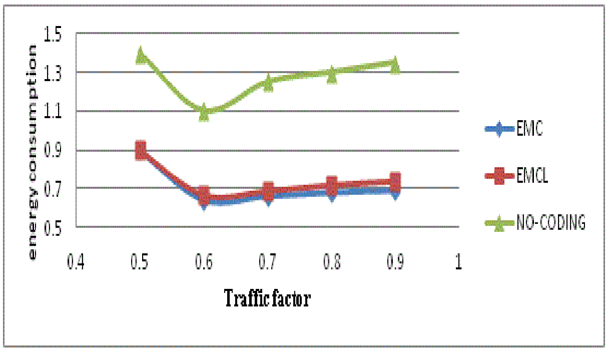

Fig. 15: The Impact of Traffic Factor on Energy Usage.

Remaining Energy is calculated as follows:

Remaining Energy= Initial Energy - Consumed Energy

The fig.16 plots a graph of EMC vs EMCL to analyze the remaining energy with different traffic factors. The graphical outcome shows that EMC and EMCL offer more residual energy when compared to the traditional protocol. Main reason for this is, as the traffic increases at the nodes, coding possibilities increases and therefore residual energy increases

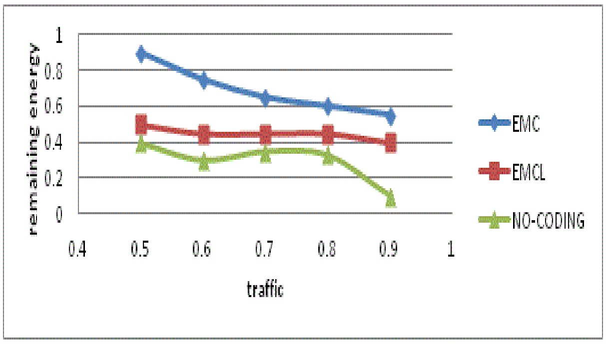

Fig. 16: The Impact of the Traffic Factor on the Residual Energy.

The fig.17 plots a graph of EMC, EMCL vs NO-CODING to analyze the manner in which the channel capacity influences the rest of the energy. The best distribution of residual energy is accomplished by EMC. The main reason for this is, the greater the space for routing the traffic through the path, the higher the coding opportunities at the nodes. This provides more possibilities for network coding and therefore reduces the energy consumption and increase the remaining energy of nodes.

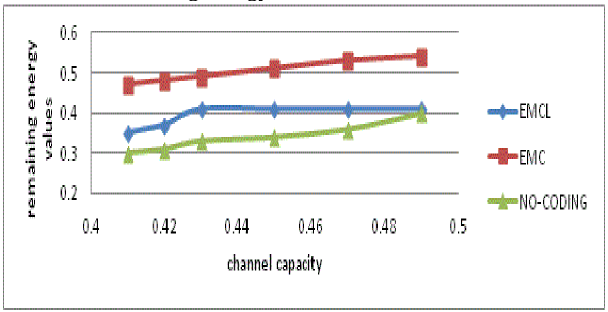

Fig. 17: The Impact of Channel Capacity on Residual Energy.

3. Conclusion

The research work presented in this paper focused on developing network coding aware routing based on AODV routing protocol. In this work, we explored network coding possibilities in different topologies and also minimizing he energy consumption together with enhancing life time of the network. The proposals made in this research work where implemented successfully in NS-2.Through exhaustive experimentation it is proved that our proposed network coding aware routing protocols resulted in high throughput with minimal energy consumption and an extended life time of the network when compared to the existing AODV routing without network coding. This research can be further explored for load balancing as well as security related issues.

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