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Adaptive Network Coding In MANET

Author
Sugumar, Shobhana

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ADAPTIVE NETWORK CODING IN MANET

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Shobhana Sugumar

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The Thesis of Shobhana Sugumar
is approved:

____
Professor Hamid Sadjadpour, Chair

____
Professor J J Garcia Luna Aceves

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Professor Farid Dowla

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Tyrus Miller
Vice Provost and Dean of Graduate Studies

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ABSTRACT

SHOBHANA SUGUMAR

ADAPTIVE NETWORK CODING IN MANET

Network Coding provides some benefits in terms of performance efficiency and throughput in dynamic environments such as Mobile Ad Hoc networks. However Network Coding also adds considerable overhead and computational complexity at the transmitter and receiver. Hence the need to come up with an algorithm to provide the optimum performance with minimum overhead and computational complexity arises. We propose an adaptive network coding technique that enables the source node to switch between storing and forwarding the original packets into the network and performing Random linear network coding (RLNC) of the packets of a file and send the coded packets into the network. We evaluate the performance of this adaptive technique by comparing it with MANETs with and without network coding. According to the adaptive Network Coding strategy, the source nodes, make the decision of switching network coding ON and OFF based on the size of the file, the estimated link expiration time between the nodes and the data rate of the network. We propose to switch off Network Coding in the nodes transmit the packets of the file directly when the File size is lesser than the maximum data that can be transmitted with the given data rate of the link and the estimated link expiration time. Otherwise the nodes switch On Network Coding and send coded packets into the networks.

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1. INTRODUCTION

In terms of Communication, there exists large number of networks that fall into one of the following categories of Peer-to-Peer networks, Internet, telephone network, wireless ad hoc networks, etc. The main aim of the research in these fields has been to increase the throughput capacity of these networks with high reliability, robustness and security. The routing strategy in general involves the flow of packets from Source to Destination node where the Intermediate node simply replicates and forwards without any processing on the received packet. The Network Coding (NC) [1] technique emerged as a promising technique during the last decade improving the throughput of the networks. Network Coding allows the nodes to combine the packets and make linear combination of the data before forwarding it to the next node instead of simply storing and forwarding. In Network Coding, the routers and switches have the capability of encoding of the incoming packets and transmitting them to the neighbor nodes. If N packets in the source node are encoded together, one innovative packet is formed. The receiver needs a minimum of N such innovative coded packets to be able to decode all the N packets sent by the source node successfully. Network Coding in the wired industry started since the first Network Coding paper [1]. This triggered lots of research activities to investigate the viability of network coding concept in the wireless industry. Network coding was more suitable in the Wireless Communication due to the broadcast nature of the channel. The nodes in the wireless channel broadcast their packets into the channel instead of routing it. This gave way to the NC Aware routing protocols in wireless ad hoc networks which is a technique that combines the Opportunistic Routing and Network Coding. Opportunistic routing [2] which allows the intermediate nodes to mix the incoming packets and forward them to the destination meeting certain conditions. NC Aware routing looks for network coding opportunities in the network and accordingly forwards the packets. Multiple neighbors overhear the packets that are transmitted. On receiving the packet only a selected set of nodes continue to forward the coded packets. The broadcast nature of the wireless channel provides an added advantage to this opportunistic routing technique and increases the throughput considerably ensuring reliable transmissions. Our work is inspired by efficient peer to peer file swarming protocol in MANET proposed by Uichin Lee et al. [3]. This study showed the use of random linear network coding for a peer to peer file swarming protocol in MANET. We propose to improve the performance of the MANET by enabling the source node to switch on and off the Network Coding technique based on the size of the file, the estimated link expiration time between the nodes and the Data Rate of the network. We aim to reduce the overhead and the computational complexity involved in the process involving network coding by dynamically changing the way the source node sends the packets into the network. They either send the packets as such into the network or code them together using Random Linear Network Coding [4]and send the coded packets into the network.

2. NETWORK CODING

Network Coding is a technique that works in contrast to the "store and forward" technique of the conventional communication systems. It allows the nodes in the network to combine the packets together to form a coded packet and send it into the network instead of simply forwarding the individual packets into the network.

2.1 RANDOM LINEAR NETWORK CODING

The large file that is to be sent in the network is divided into several blocks. If we consider the whole file as a single block of data, then the computational complexity involved in encoding and decoding will be very high. The packets are encoded i.e. a linear combination of original packets is generated and transmitted. The receiver node receives the encoded packets and decodes them to obtain the original packets back. This process is described as Random Linear Network Coding.

2.2 RATELESS CODING

Rate less coding means any number of representations of the original packets can be created when compared to certain codes with a rate where only fixed number of representations is possible.

2.3 FINITE FIELD

Finite field is a variable which specifies the rules for the arithmetic operations. The rules make sure that the result of working on a finite field will result in a value that is present in the field.

2.4 ELEMENT

An element is an element of the finite field.

2.5 SYMBOL

A symbol is defined as a vector of the Finite Field. The size of the symbol depends on the size of the element and the number of elements in the symbol.

2.6 GENERATION

Each generation consists of “g” symbols each of size “m”. “g” is called the size of the generation. A file may consist of a single or multiple generations. Each generation is encoded and decoded separately.

2.7 CODING VECTOR

A coding vector is a vector of coefficients picked from the finite field for each symbol in the generation.

2.8 CODED SYMBOL

A coded symbol is generated by multiplying the original data with a coding vector. This process is called encoding.

2.9 CODED PACKET

A coded packet is a packet that contains the coded symbol and the coding vector coefficients in the header.

2.10 LINEAR DEPENDANCY

A coded packet is said to be linearly dependent or non-innovative with respect to the previous coded packet if it is a linear combination of the already known symbols.

2.11 ENCODING

The symbols of the generation are multiplied with a randomly generated coding vector which is of length equal to the size of the generation. When transmitting a coded symbol into the network, the coding vector is attached to the header of the coded packet and sent across the network.

2.12 DECODING

For the receiver node to be able to successfully decode a generation of symbols, it must have received at least “g” linearly independent coded packets. The original data is retrieved by performing a Gaussian elimination method, with the coding vectors of all the coded symbols known by the receiver.

3. NETWORK CODING FILE TRANSFER PROTOCOL

In this section we describe the file transfer protocol that uses network coding. Let the source node S is assumed to have the file to be transferred into the wireless medium. The File F is divided into n packets $p_1, p_2, p_3 \ldots \ldots p_n$. These packets are coded into one coded frame Q_k also termed as one innovative packet. Thus innovative packet is a linear combination of the packets of the file F.

$$Q_k = \sum_{k=1}^{n} Ck \, . \, Pk$$

C_k is an element of a certain finite field . GF(256) is used in order to obtain a randomly linear and independent coded packet. When the source node tries to generate a coded packet, C_k is drawn randomly from the GF (256) thus giving the name Random Linear Network Coding. The header of the coded frame contains the coding coefficients so that this can be used by the destination node in decoding the original packets of the file. The node then transmits these innovative packets into the wireless channel.

$$\begin{pmatrix} Q1 \\ Q2 \end{pmatrix} = C * \begin{pmatrix} P1 \\ P2 \end{pmatrix}$$

Where $C = \begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix}$ is the coding coefficient matrix.

Once the destination receives N such innovative packets, it will be able to decode the original N packets $p_1, p_2, p_3 \ldots\ldots p_n$ of the file F. The above process describes the coding process of the source node.

$$\begin{pmatrix} P1 \\ P2 \end{pmatrix} = C^{-1} * \begin{pmatrix} Q1 \\ Q2 \end{pmatrix}$$

Let us consider the scenario of the intermediate node that receives a number of coded frames. This intermediate node re-encodes the coded frames that it received and transmits this newly coded frame into the network. The coding coefficients for the re-encoding process is also taken randomly from the GF(256). Every intermediate node receives the coded packets even though they are not the destined nodes for those packets. It stores the coded frame into its local memory after making sure that the packet it received is an innovative one and linearly independent to the coded frames present in its local memory. Every node promiscuously listens to the packet. It overhears the packets and stores them in its local memory. These coded frames are re-encoded and transmitted to the other nodes in the medium. Re-encoding is proven to increase the efficiency when compared to end to end coding. If the file size is large, then the file is divided into smaller files which are in turn divided into packets and combined using Random Linear Network Coding which reduces the size of the coding coefficients and in turn the computational complexity. The destination node decodes the coded frames using Gaussian Elimination by solving a set of linear equations and obtaining the original packets. This process is continued until the destination node receives the entire file.

4. PREVIOUS WORK

The authors in [5] aim to provide an adaptive network coding based on the contents interested by different users. The idea is to match the social interest similarities of the people in a community. Consider two different contents in the network i.e. I1 and I2. The people in the community are interested in one or both the contents in the network. A person who is interested in content I1 has a better chance to meet a person who is also interested in I1. Hence in a sparse connection scenario, if we are to traditionally code all the contents together (I1 + I2) and send them, a person who is interested in decoding only I1 will need to wait until he receives I2 as well. Thus the decoding delay is increased in a sparse connectivity scenario. Consider 8 different destinations waiting for different contents. Each content contains various number of messages, I1 to I8 (110 to 2 msgs). CBnetCod designed in this paper demonstrates that the destinations waiting for 2 messages get lower decoding delays than the one that is waiting for 110 messages. This technique will extremely reduce the decoding delay for the destinations however this might lower throughput considerably. In order to find the perfect tradeoff between the decoding delay and throughput, they propose to define a parameter that allows mixing of the content in certain cases only. When everybody wants everything, the most optimal method would be to mix all the traffic together and broadcast the same.

The past adaptive routing protocols lack the important context information which is important in efficient estimation. Context information is application specific. It typically defines the nodes mobility, its future movements and how data is being transmitted. In [6], the authors propose the concept of using the external context agents to monitor the context in a dynamically changing environment. An adaptation portal is designed as an interface between the router and the Context agent. The Context Aware network Coded Context (CANC) agent reconfigures the behavior of the routers dynamically adjusting to the changes in the environment. The context agent provides the context information through source contacts, link performance and the mobility of the nodes. The Context aware adaptive routing (CAR) proposed previous to this paper uses the mobility of the nodes and the contact pattern to fetch the best next hops during routing decisions. This paper also proposes a framework for integrating the context information with any Delay Tolerant Network (DTN) router. In establishing the CANC Adaptation portal, three parameters are used for the flow control of the encoded bundles in the protocol. The rate at which the packets are sent from one specific node to its neighbors. A node that has a higher rate is selected when determining the route. Each GUID bundles have a specific rank. The GUID bundle that has the highest rank is selected and favored. When a node has two or more neighbors and the links sharing the same channel bandwidth, the node may decide to bias the bandwidth to a particular neighbor that is information starved part of the network in order to balance the network.

Intersession Network Coding (NC) enables the processing of the information locally and mixing of independent traffic flows. Capacity is increased when we combine the flows. However, such increase is seen only when, routers are able to quickly identify efficient coding opportunities, packet decoders are able to correctly decode the encoded packets and acknowledge them. However NC can increase the router throughput in random-access networks, prior studies have shown that when the packets are scheduled carelessly, the benefit is reduced. With multi-rate links, and when decisions are made based on statistical information, scheduling is necessary to avoid packet losses. All these factors should be taken into account when designing and developing practical NC algorithms and systems. A new protocol called NCRAWL [7] proposes a more modular scheme realizing joint NC and scheduling, utilizing solely the stochastic information for overhearing. This protocol is also made channel aware. The design of NCRAWL facilitates lower overheads, thereby, performing all the NC functionalities and approaching the expected capacity benefits of combining joint NC and scheduling.

This paper [8]proposes a multicast scheme in tactical MANETs using network coding that is resilient to jamming. Each node dynamically adjusts coding rate and the forwarding rates based on channel condition. If channel condition deteriorates, the node generates and forwards more coded packets. Each intermediate node includes its rank of the current generation in the packet header, and an up-stream node adjusts forwarding rate based on the overheard rank information of down-stream nodes. This avoids the need for the special radio system and the need for the topology.

The authors in [9] propose the design of coding-aware and rate-adaptive multiple path routing mechanism. This protocol makes routing decisions with the awareness of coding opportunities and splitting traffic of a flow to maximize the coding opportunities in the network. The contributions of this paper are as follows. The paper proposes a coding-aware routing mechanism, which makes routing decisions based on node-centric metric instead of link-centric metric as used in other existing work, in order to discover coding opportunities as much as possible. Second, the protocol works in a rate adaptive manner and it splits one flow onto multiple paths, which can utilize coding opportunities effectively and balance network load. Third, routing decision at each and every node is done in a localized manner.

5. ADAPTIVE NETWORK CODING ALGORITHM IN MANET

By reviewing the works mentioned in the previous section, we realize that Network Coding offers significant benefits in dynamically changing environments such as wireless networks and DTNs where the nodes are constantly moving and rapidly changing direction and speed. It provides optimum throughput and performance when compared to sending the packets using the traditional “store and forward” method. Network Coding involves some overhead as it is necessary to send additional information about the coding vectors in the coded packets. However the size of the coding vector is small when compared to the packets. The size of the coding vector depends on the Galois Field size and the number of symbols in the generation. The decoding delay involved while Network coding the original packets depends on the generation size. With the disadvantages and the advantages of Network Coding known, it was necessary to come up with an algorithm that switches ON and OFF Network Coding under certain conditions to maintain the optimum percentage of delivery and performance with considerable less overhead and computational complexity.

The following Analysis is made on Mobile Ad Hoc Networks (MANET). MANET is a self-configuring network of mobile devices connected wirelessly. Each device in the MANET is free to move continuously in any direction and speed, therefore the connectivity between the nodes in the network frequently changes. Each node in the network acts as a router and routes the packets between the nodes based on the routing protocol. The link expiration time is the time by which the two nodes move out of the communication range of each other is an important factor while considering file/packet transfer.

Let F be the size of the file in bytes. We define 8*F as the file size in bits, R as the data rate in bps, and T as the estimated link expiration time between the two nodes in seconds. The maximum data that can be transmitted between the nodes before the link between the nodes expire is R*T bits. When the actual file size 8*F bits is smaller than R*T bits, then there is no need to network encode the packets and transmit and instead just transmit all the packets of the file within the meeting time thereby avoiding the overhead and the computational complexity involved in performing network coding. When the file to be transmitted is larger than the maximum data size that can be transmitted within the given data rate of the link and the estimated link expiration time, then the source node decides to perform network coding and transmit the coded packets into the network.

If R*T >= (8*F) Switch to Network Coding and transfer coded packets

Else if R*T < (8*F) Turn off Network Coding and transfer original packets.

The Estimation of the link expiration time (LET) between two nodes used in this thesis is based on a previous work in [10]. In this paper they propose mobility prediction to improve the unicast and multicast routing protocols. The scheme that they propose utilizes the GPS location information to estimate the link expiration time. The GPS location information is piggybacked on the data packets. They proposed the following expression to estimate the link expiration time between the nodes.

Let (x_i, y_i) be the coordinates of the node i and (x_j, y_j) be the coordinates of the node j. v_i and v_j be the speeds of the two nodes and θ_i and θ_j be the moving direction of the two nodes i and j respectively. When two nodes i and j are within the transmission range 'r' of each other, the amount of time the two nodes will stay in the communication range of each other is given by

$$\text{LET} = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2},$$

Where a = $v_i cos\theta_i - v_j cos\theta_j$, $b = x_i - x_j$, $c = v_i sin\theta_i - v_j sin\theta_j$ *and* $d = y_i - y_j$ .The adaptive network coding methodology proposed in this thesis, uses the Link expiration time proposed above by William Su et al. [10].

6. EXPERIMENTAL SETUP AND EVALUATION

In this section, we evaluate and compare the performance of the proposed Adaptive Network Coding approach for MANETs with Network Coding and without Network Coding. We implemented the code by integrating the Network Simulator NS3 [11] and the Network Coding simulator code – Kodo [12] to perform the simulations for the MANETs with Network Coding and Adaptive Network Coding approach. The simulation modelled a network of mobile hosts placed at random locations within a 2000 x 2000 square meter area. The data rate is fixed at 1Mbps.

The mobile hosts move based on the Random Waypoint Mobility model. AODV is the underlying routing protocol. 50 seeds of simulations for multiple flows of different file sizes were run and the percentage of delivery and the average delay for receiving the entire files were computed. It can be seen from Figure 1 that the percentage of delivery remains the same for MANETs with NC and Adaptive NC. The performance is not affected much; however in the MANETs without NC i.e. nodes performing the store and forward mechanism of packets, the delivery percentage starts to deteriorate for higher file sizes. Link Failures are handled by the underlying routing protocol, in our case the AODV where in the RERR (Route Error) messages are sent and new route discovery process in initiated. When more and more nodes breakdown, the percentage of delivery goes down, however this would be smooth and comparatively better than other approaches. We next compute the average delay for transmitting the file to the destination for various file sizes. The results can be observed in Figures 2, 3, and 4.

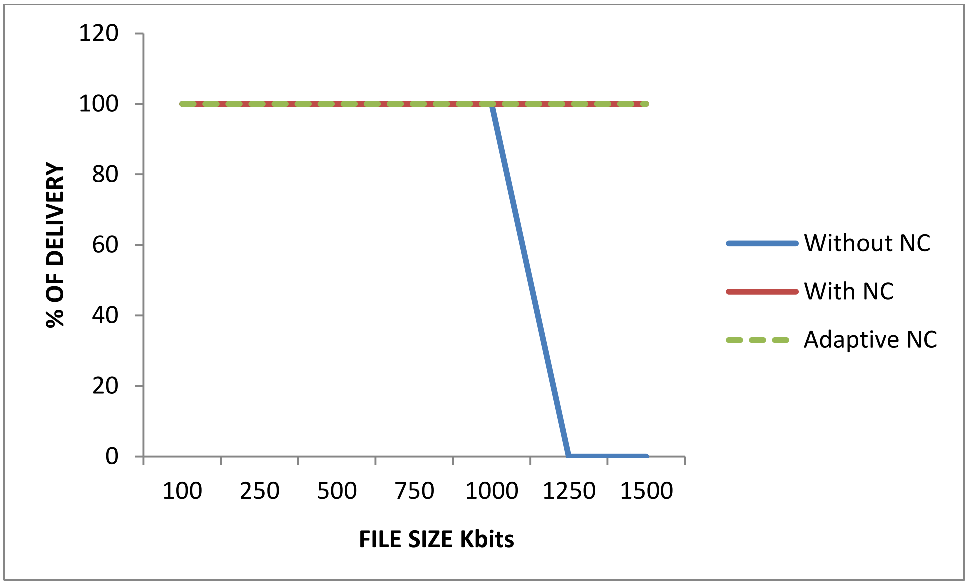

Figure 1: Percentage of Delivery Vs File Size Comparison for MANET with Network Coding, Adaptive Network Coding and without NC

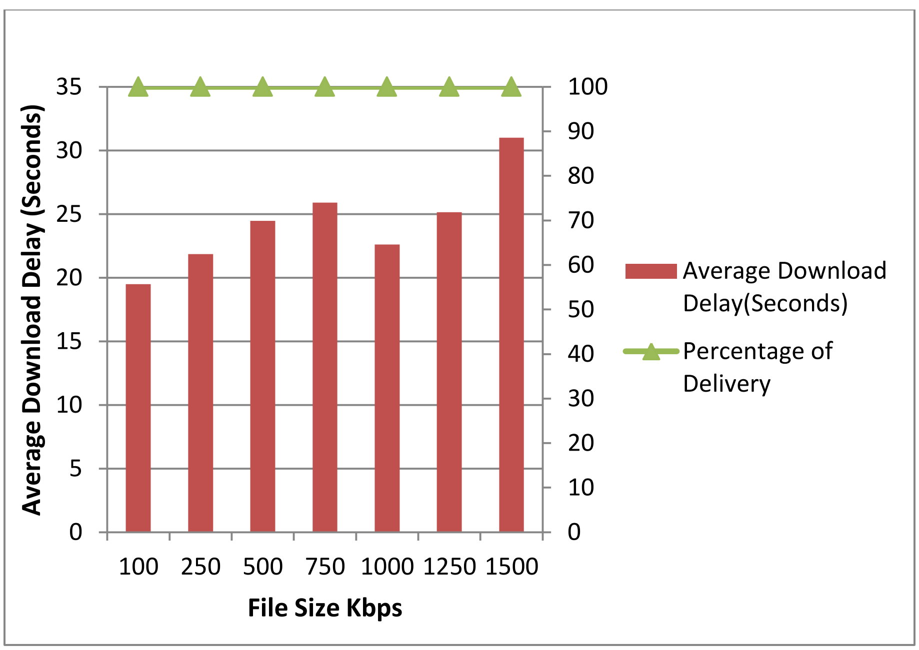

Figure 2: Average Download delay Vs File Size for MANET with Network Coding

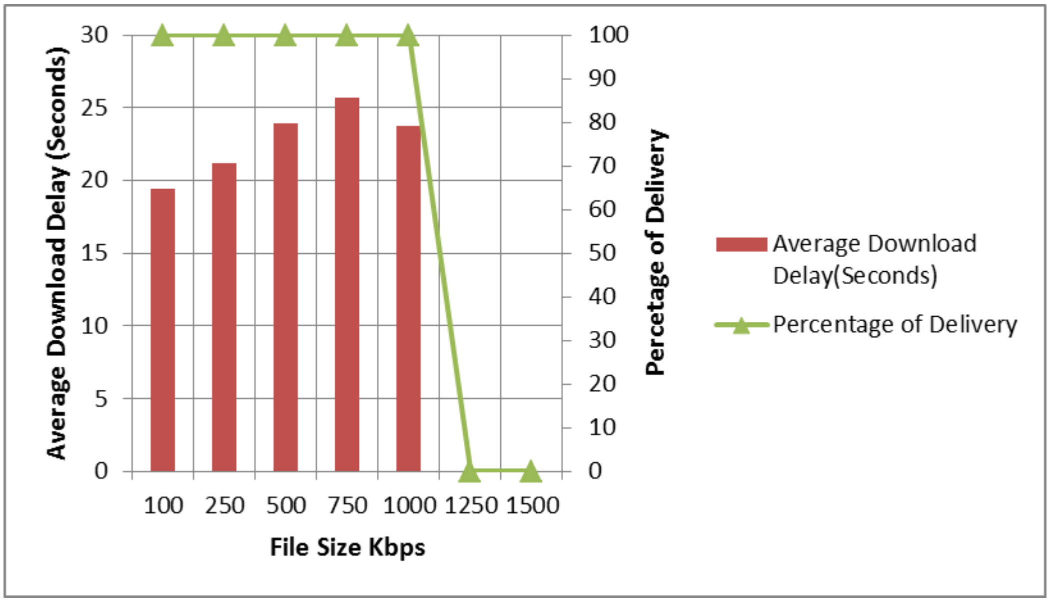

Figure 3: Average Download Delay Vs File Sizes for MANET without Network Coding

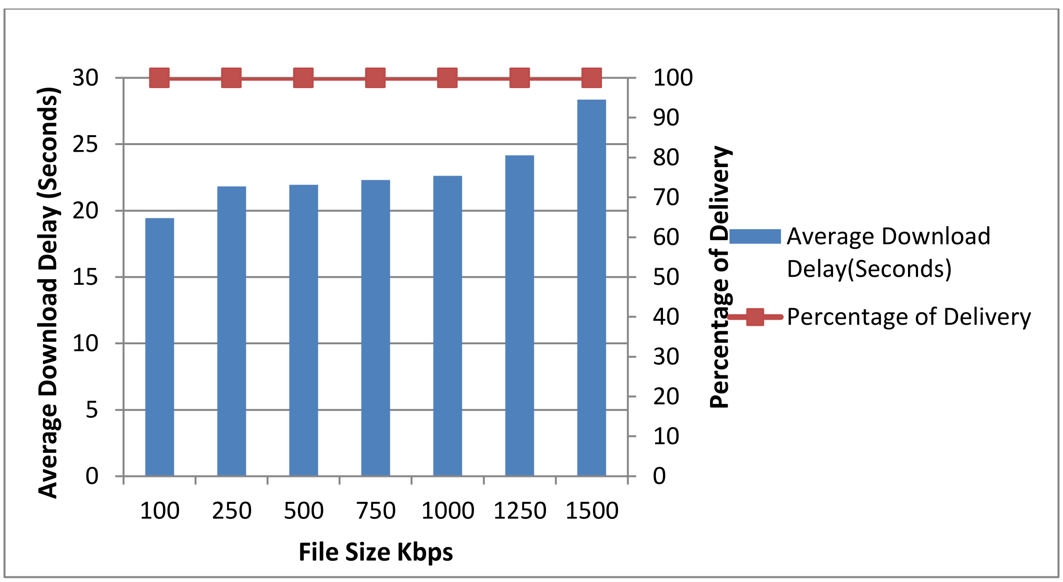

Figure 4: Average Download Delay Vs File Size for MANET with Adaptive NC

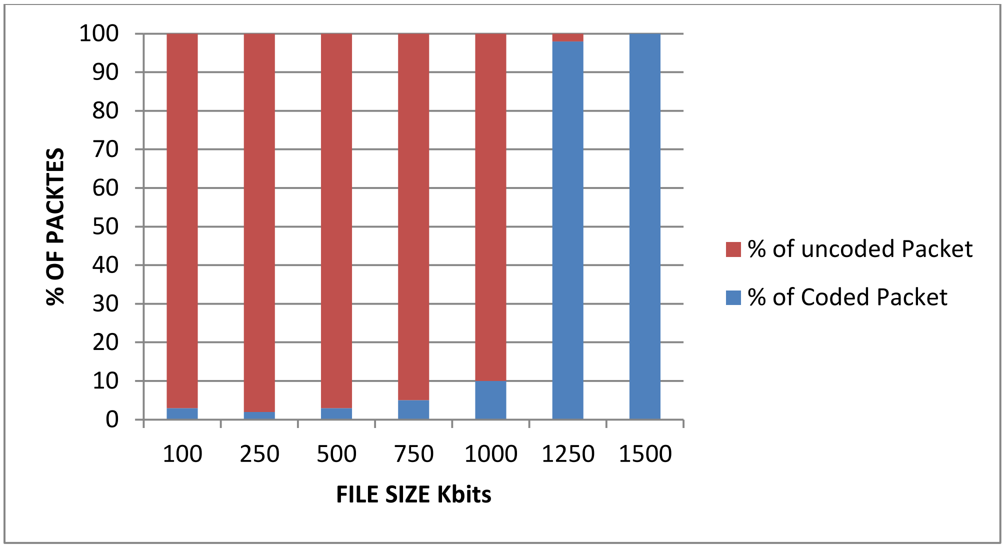

Figure 5: Percentage of coded and uncoded packets Vs File Sizes for MANET with Adaptive NC

From Figures 2, 3, and 4, we conclude that an acceptable download delay can be achieved with adaptive NC when compared with the other approaches. From figure 5, we see that the Adaptive NC is being able to switch between NC and the store and forward packet transmission, thereby avoiding transmission of coded packets, which is not suitable for flows with small file sizes. The Network Coding approach approximately adds 6% of the packet size as overhead in order to send the additional coding vector information needed for decoding. Thus the overhead and the computational complexity can be reduced considerably, when we employ the adaptive NC when compared to MANETs with regular NC.

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