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PERFORMANCE EVALUATION OF H.264 PROTOCOL IN AD HOC NETWORKS

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Wireless mobile ad hoc network data transmission between multiple senders and receivers is becoming increasingly important in nowadays networks. There are many applications for sending data from a single source to multiple destinations (e.g. broadcasting) or from multiple senders to multiple receivers (e.g. teleconference). A wireless Mobile Ad hoc Network (MANET) or a multi-hop network is a collection of wireless mobile hosts forming nodes that arbitrarily and randomly change their locations. No centralized administration or infrastructure is supported, and each host communicates via radio packets. Nodes are responsible for establishing and maintaining connections between themselves. Such dynamic topology of MANET leads to several unique design issues that do not exist in other wireless networks. Video transport over ad hoc networks is more challenging than that over other wireless networks. The wireless links in an ad hoc network are not error resilient and can go down frequently because of node mobility, interference, channel fading, and the lack of infrastructure. Moreover, typical video applications may need a higher bandwidth and higher reliability connection than that provided by a single link in current or emerging wireless networks. On the other hand, it is possible to establish multiple paths between a source and a destination. Transporting video over wireless networks is further constrained by: delay limits, power issues and quality of service (QoS) parameters. All of these points should be handled carefully in video transport services. The goal of this research is to calculate the maximum distance, or number of hops, that can be supported in an ad hoc network while maintaining the delay constraints and reasonable quality of service (QoS). In this paper, we will evaluate the performance of H.264 protocol using two routing protocols, mainly: the Neigbhor-Aware Clusterhead (NAC) and the Dynamic Source Routing (DSR) protocols. The simulation results show that it is feasible to have video over ad hoc within an average distance of 6 hops utilizing an average of 5.5 Mbps, however the performance varies from one protocol to another.

Key words: Ad hoc networks, video streaming, performance evaluation, acceptance criteria

1 Introduction

An ad hoc network is a concept of computer communications, which means that users waiting to communicate with each other to form a temporary network without any form of centralized administration. One of the main features of ad hoc networks is that the network will not collapse just because one of the mobile nodes moves out the transmitting range of the other nodes. Nodes are able to join or disjoin the network at any time. In others words, ad hoc networks are capable of handling topology changes and malfunction in nodes. In ad hoc networks, each host must act as a router, since routes are mostly multi-hop. Due to the continuous movement of the nodes, the backbone of the network is continuously reconstructed. Moreover, the nonexistence of a centralized authority also complicates the problem of medium access.

Video data is normally contains a lot of redundancies. This redundancy wastes an ample amount of bandwidth if we send the data without any compression. Applying compression techniques generally will reduce the bandwidth required by a factor of 70% or more. Therefore, it is in practice for video data to compress it before transmission.

Today, many video compression standards are available with different pros and cons and are suitable for different data rate, video quality and QoS. Among the standards, two major groups are very active in this area, namely: International Telecommunication Unit (ITU) and Moving Pictures Experts Group (MPEG). H261, H262 and H263 are popular ITU video standards while MPEG1, MPEG2, MPEG3, MPEG4 and MPEG are some popular ones from MPEG. H.263 is a low bit-rate compression scheme which is extremely useful for wireless networks and also for video data where there is little or no motion such as still video. Performance is sharply degrades with increased in motion in case of H.263.

In May 2003, a new popular and efficient standard (H264 /MPEG4 AVC) was launched by joint venture of both the aforementioned groups [1]. It has many interesting and easy-to-use features on account of which it has received the attention of many researchers in this field. Hence, it is reasonable to highlight some comparative key features to this standard in more details.

2 Related Work

Real time traffic over ad hoc network is important in two aspects. Firstly, the gradual popularity of ad hoc networks especially for certain circumstances such as research conferences and exhibitions. Secondly, there is a need to make all kinds of network suitable for real time traffic. Thus, on discussing the related work, we find research in both areas. Some researchers have focused on ad hoc routing protocols to optimize the overall performance, while other researchers have reflected more interest in user's data rate and codecs used for compression/decompression. The authors in [2] introduced multistream coding with MultiPath Transport (MPT) for video traffic over ad hoc network. In their approach, a video bit stream is divided into several substreams by the video encoder and then packets from different substreams are sent over different paths. At receiver, the process is reversed. Moreover, to make multi-streaming appropriate for ad hoc network, the study proposed three different multi-streaming techniques each has it own advantages. They show, by Morkovian model and OPNET modeler, that there is a considerable improvement in video quality if we make use of this concept. However, they overlooked the use PCF mode in their OPNET simulation which should have been tested. The authors in [2] introduced the ideas of multi-streaming or multi-flow of a given video data as shown in [3], and then in MPT [4]. Also, the three coding schemes they made use of in [2] have been described in detail in [5][6][7]. An interesting analysis is carried out using H264 video standard to study video transport over ad hoc networks in [8]. The simulation showed that packet size of as small as 300 bytes should be used under unfavorable condition as any increase results in degradation of Peak Signal to Noise Ratio (PSNR). For higher error probabilities, even smaller than 300 bytes is good for significant PSNR. Regarding retransmission attempts, 3 per Message Protocol Data Unit (MPDU) gives highest achievable PSNR. Increasing beyond 3 gives no fruit as far as PSNR is concerned. This is useful analysis and good approximation to calculate packet size, error probabilities, etc. for a given PSNR. However, no analytical support is presented to their simulation results nor they exploited the idea of MPT. We believe that if we extend this simulation using the investigated protocols with the introduction of MPT concept, we will be able to get better performance (i.e. higher PSNR with larger packet size and smaller retransmissions). Moreover, their experiments appear to be applicable for static devices and do not give any guarantee when mobility of the devices is considered.

Among the three schemes described in [2], Multiple Description Motion Compensation (MDMC) is unique in the sense that it gives better error resilience on loss packet networks. The main idea is to combine all the correlated bits to give acceptable quality reconstructed received signal. The study in [9] provided analytical model to prove this feature of MDMC. Furthermore, the proposed analytical model has also been tested by simulation. While the above discussion is related to video standards or ad hoc networks algorithm to improve the performance [10], in general for wireless networks how to obtain optimal data rate for video traffic is important. In real network traffic, there is a loss of packets due to poor efficiency of the antenna, interference, fading, and weather conditions, etc. resulting in need for retransmission (ARQ) or some mechanism to recover the original signal (e.g. FEC). The work presented in [10] developed dynamic strategies for FEC (e.g. no redundant packets) and ARQ (e.g. dynamic change in transmission rate) in order to meet certain QoS requirements. Moreover, buffers of client and server play an important role in delay jitter (in ARQ). Hence, they also developed a control mechanism for buffers with the notion to minimum delay jitter. In the light of previous discussion, it is clear that the use of MPT provides more flexibility over data rate. We would be able to achieve higher data rate if paths are independent. Buruhanudeen in [11] enhanced this approach and presented an analytical video distortion model. Buruhanudeen also claimed that the cause of distortion is due to two main factors: encoder distortion and packet loss due to congestion. In [11] also presented a tradeoff using simulation between data rate and congestion. Moreover, what is appealing in the comparison results of encoded transmission and decoded transmission which give a quantitative measure of how much distortion is added due to congestion. What have been discussed so far leads us towards MPT concept. Yoo et al. in [12] introduced a new concept of cross-layer design framework for real time traffic using H264 codec. The main idea behind their approach is that the scheme tries to make maximum use of network resources such as bandwidth, etc. where the traffic is in progress (being transmitted). To avoid congestion, traffic flows and link capacities, on the chosen links, are allocated together. Their simulation shows improvement over traditional schemes in terms of data rate and PSNR. The improvement is multiplied further if we combine MPT with cross-layer design. Power consumption is also a major concern in wireless ad hoc networks as all node's activity is dependent upon battery life. Moreover, transmission with more power is harmful to human beings. The approached presented in [13] made use of HCB and RM models for ad hoc routing such that the power consumption is minimal most of the time. HCB model behaves well for short term transmission, whereas the results are better obtained by RM for long term communication, far away devices. In our approach, we only used local version of power saving model [13] which was referred to it as HCB model in [14]. This model minimizes the power locally and then propagates this procedure (using Dijkstra algorithm) till the destination is reached; thus, forming minimum power topology.

2.1 Video Compression Standards

It is important to note that why there are so many video compression standards in the market. From literature, we found that standardization enables communication between devices made by different manufacturers thus promoting a technology or industry and reducing costs at the same time. It implies that compatibility, production and cost are the three main focuses for video standards.

Figure 1: Scope of standardization

The next issue is what to standardize and what not. Practically, just the bit stream syntax and the decoding process (e.g. use IDCT but not how to implement it) are standardized while encoder and decoder are left to the companies to make them suitable to meet these standardization rules, as shown in figure 1. This concept provides ways as to how improved encoding and decoding strategies to be applied. Moreover, there is no problem in interoperability if bit streams is standardize and do coding process and leave codecs to the developers.

2.2 H264 Standard

H264 is a high compression digital video codec standard written by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC MPEG as the product of a collective partnership effort known as the Joint video team (JVT) [15]. H264 has multi-picture motion compensation up to 32 reference pictures that can be used; thus, allowing improvements in data rate and video quality. The variable block size, from 16x16 down to 4x4, quarter pixel precision (MC precision of 1/8th pixel is possible), and deblocking filter for finer tuning in picture shape. Its filter strength depends on the prediction modes and relationship between the neighboring blocks and 4x4 linear DCT, before it was real, so computationally easy.

The Network Abstraction Layer (NAL) provides more robustness than H263 and flexibility and is designed to provide network-friendly video representation. Also, the data is partitioned a feature that providing the ability to separate more important and less important syntax elements into different packets of data. The entropy coding of the transformed residual coefficients supports data such as motion vectors.

In H264, multiple reference frames provide additional flexibility for frames to point to more than one frame, which may be any combination of past and future frames. This is helpful for more precise inter-prediction and it also improves robustness to lost picture data. Moreover, unrestricted motion search, which is an optional feature and can be disabled, thus enabling restricted motion search. This feature allows for reference frames that may be partly outside the picture.

The slice coding to mitigate errors, network variability and packet losses, each frame is subdivided into one or more slices. This is to ensure that errors or missing data from one slice do not propagate to any other slice within the picture (frame). These are some of the commonly known features but the main goals of this standard are to provide compression performance and video representation addressing video telephony and non-conversational such as storage, broadcast, or streaming applications suitable for network environment [16]. The following a broad list of the applications where H264 can be deployed:

- Broadcast over cable, satellite, cable modem, DSL, terrestrial, etc.
- Interactive or serial storage on optical and magnetic devices, DVD, etc.
- H264 DVB over IP Broadcast Encoder, details are available in [17].
- Conversational services over ISDN, Ethernet, LAN, DSL, wireless and mobile networks, modems, etc. or mixtures of these.
- Video-on-demand or multimedia streaming services over ISDN, cable modem, DSL, LAN, wireless networks, etc.

- Multimedia messaging services (MMS) over ISDN, DSL, Ethernet, LAN, wireless and mobile networks, etc.
- Any video application can benefit from a reduction in bandwidth requirements, but highest impact will involve applications, where such reduction relieves a hard technical constraint, or what makes more cost-effective use of bandwidth as a limiting resource.
- Finally, it is especially useful for IP and wireless environments which forced us to use this standard in our simulation.

In our simulation, we utilized Quarter Common Intermediate Format (QCIF), compression 7:1. After compression, the bits are packetized into fixed packet size of 4pps (64.76kbps). More specifications are provided in table 1. The detailed description and analysis of H264 can be found in [1].

Data Rate	64.76kbps
Average Compression Delay	75msec
Average Power Consumption	100mW

Table 1: H264 specs.

2.3 Neighbor-Aware Clusterhead (NAC) Overview

In this section, we describe the neighbor-aware clusterhead infrastructure protocol [18]. Each group of nodes is served by a clusterhead. The number of neighbors served by a clusterhead is optimized using the Local Information No Topology (LINT) and Local Information Link-State Topology (LILT) protocols [19]. Also, nodes are allowed to go to sleep mode and are synchronized with their clusterheads using Reference Broadcast Synchronization (RBS) algorithm [20]. Each clusterhead acts as a reference node and broadcasts reference time to all Zone_MTs to synchronize their clocks. Moreover, even within the same cluster, cooperative routing can be applied in case of non-real time traffic, i.e. if delay is not an issue of concern. However, in this work, since we are dealing with real time traffic, we will apply direct transmission. We used modified version of the delay efficient sleep scheduling (DESS) protocol [21] to schedule sleep periods. Each node picks a unique time slot within its cluster broadcasts to its neighbors. More detailed description of NAC protocol can be found in [18]. This protocol will be compared together with DSR protocol [29][30].

3 HCB AND RM Models

In this paper, delay metrics (end-to-end, hopwise and jitter delays) have the highest priority, nonetheless, power conservation of utmost important. There has been emphasis on power preservation to last for longer time, without recharging, and many researchers have focused on this specific issue [13][14][22]. We also minimize power to an extent that it does not degrade improved delay performance. HCB and RM power model can be used to minimize/optimize power operations. HCB minimizes the power locally and then propagates this procedure using Dijkstra algorithm, till the destination is reached; thus, forming minimum power topology [22]. It should be noted that this creates a delay due to the large number of hops involved in this technique. In other words, there is a trade-off between maximum delay and power reduction. Hence, we do not apply HCB model (cooperative routing), we rather apply RM power model even though it consumes more power.

4 Delay Model

As we mentioned above, video data is very sensitive to delay, the data has to be received before a maximum threshold of delay of 250 msec, and the reception of data is of no use. Therefore, special care must be carried out to minimize the delay as much as possible.

Let us assume that the maximum number of hops of an ad hoc network equals to n_h^{max}. Suppose that A be the area of the network and N be the number of nodes present within A. Let d_h be the distance between two nodes. Assume that the nodes are regularly distributed within A. If the source and destination are placed at opposite ends of the square, then [24]:

$$n_h^{max} = \Theta(\sqrt{N})$$

For symmetric probability distribution [24], the average number of hops can be calculated using the following equation,

$$\bar{n}_h = \frac{n_h^{max}}{2}$$

In our experiments, compression/decompression delay, routing delay, CSMA/CA delay, propagation delay, transmission delay and queuing delay constitute the overall delay. Where,

- Propagation Delay = d_h /Link Speed.
- Transmission Delay = Packet Size/Link Speed.
- CSMA/CA delay depends on the network environment and varies accordingly. We have implemented CSMA/CA MAC protocol in our simulator. At the end of each experiment, we calculated the average MAC delay and we found it to be 0.33ms. This result conforms to that found in [25], which was 0.3 ms.
- Routing and queuing delays vary proportional to the traffic injected into the network, number of nodes, network conditions etc. So, if the addition of compression and decompression is about 40-60 msec, then an approximate minimum value of total delay can be calculated as:

Total Delay = 60 + 0.33 + 10 (ignoring transmission and propagation delays).

Where, 10 ms is an approximate average routing delay [26]. From the above equation, we can derive the estimated lower bound of delay, where 70<Total Delay<250. No retransmission is considered using the pervious calculations. To have more accurate estimation, we utilized the following formula [24].

$$Total\ Delay = \frac{1}{LinkSpeed}(PktSize * N_{link}^{rt})\, n_h + (n_h - 1)\, D_I\,.$$

Where, D_I is the intermediate nodes delay and N_{link}^{rt} is the number of retransmission per packet.

5 Mobility Model

Mobility model is one input parameter for the simulation necessary for development, operation and testing of the network. It has to mimic the behaviors of real Mobile Terminals (MTs). Functions like localization, routing algorithms, power control or security support must be accomplished in a distributed manner. It is common in wireless networks that the devices move within a certain range. In order to model such environment, we establish a mobility model in which the nodes can freely move. The nodes move with an average speed of 2 m/s after a short interval, which is controllable. We can change the mobility effect by changing this interval. For instance, if the Motion Interval (MI) is 30 it means that the nodes move with 2 m/s after every 30 sec. If MI is reduced to 10, then the frequency of the motion increases (i.e. the nodes move after every 10 sec). Thus, decreasing the interval yields too many disconnections, which results in more drop in the network and vice versa. In our simulation, we utilized Gauss-Markov mobility model [27]. We found it to be more realistic than other mobility models, such as random walk, random waypoint, random direction, etc. Initially, each MT is assigned a current speed and direction. At fixed intervals of time, *t*, movement occurs by updating the speed and direction of each MT. Specifically, the value of speed and direction at the n^{th} instance is calculated on the basis of the value of speed and direction at the $(t\text{-}1)^{st}$ instance and a random variable. For interested readers, more details about Gauss-Markov mobility model can be found in [27].

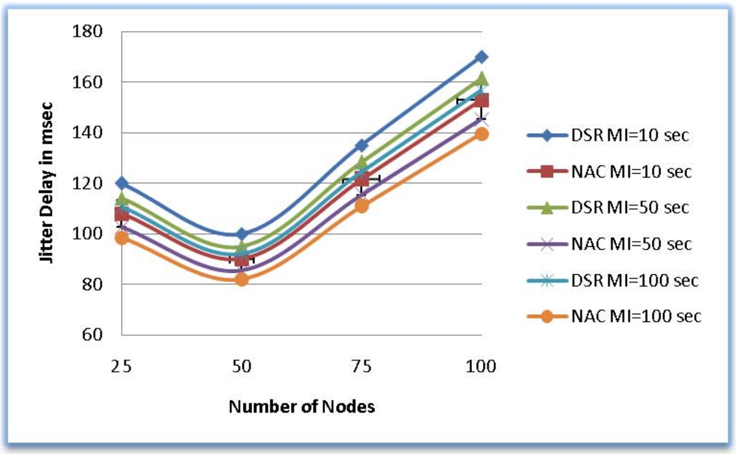
6 Performance Evaluation

In this section, we compare the NAC against DSR protocol. A packet-level discrete-event simulator was developed to monitor, observe and measure the performance of the NAC and DSR protocols. The simulator was developed using Java programming language. All the simulation experiments were conducted for ad hoc networks with 25, 50, 75 and 100 mobile terminals in 500X500 unit grid. The maximum transmission range is 50 units. Initially, each mobile station is assigned a unique node ID and a random position in the x-y plane. The energy level is above Threshold [18]. The speed is between 0 to 2 m/s. In case of NAC protocol, we set d_d to 5 MTs, which means if the number of MTs is less than 5 the power should be increased, otherwise it should be decreased. The simulator measures the following noteworthy statistical performance metrics:

1. Average delay jitter: This metric shows the per hop delay. It is very important for real time traffic, the less this number the better. The inter-arrival time of a packet at the receiver is not constant, but it fluctuates. Delay jitter is a measure of the difference of the two consecutive packets delay coming from the same source. It is mainly caused by the queuing and medium access delays in the source node, all transit node delays and the receiver buffer delay in the destination node. Similar to the above metrics, we evaluated the behavior of delay jitter by changing the number of nodes and mobility proportion.
2. Average end-to-end delay: This metric shows the end-to-end delay for successful transmitted packets. More precisely, it is the time when a packet is generated until it reaches final destination. We plot average end-to-end delay versus number of nodes and frame size. In order to see the maximum number of supported hops, we draw hop wise delay versus hop under different mobility proportion, i.e. for different MI. This means that we have also analyzed the delay variation due to mobility by changing motion interval to 100, 50 and 10 seconds respectively.
3. Hop wise Packet Delivery: It indicates the hop by hop percentage of received packets. It will help us to know at which hop the delivery is maximum for video.
4. The power in each node at the end of simulation: This metric shows how efficient the protocol in optimizing energy consumption. The bigger this number the better. We plot the mean of total consumed power by all nodes after simulation against the number of nodes utilizing RM power model. We show power saving of NAC and DSR protocols by plotting against each other versus the number of nodes.
5. Average Throughput: It is worth-noting to look at delivered packets percentage to analyze the network performance. We normalized delivered packets with sent packets.

7 Simulation Results

This section presents our simulation results. Figure 2 shows the variation in delay jitter with the increase in number of nodes. The jitter changes slowly after some transient period, where the nodes are not enough and their small number is the major cause of network disconnectivity. This is acceptable with 150 msec for low mobility (MI=100 and 50), but increases beyond the limit for high mobility. Also, it is acceptable if we compromise a little on the video quality which normally happens in wireless networks. Moreover, the mobility has a major impact on the performance of the network. As we can see that the differences between NAC and DSR protocols are not high.



Fiugre 2: Impact on the network of Jitter delay

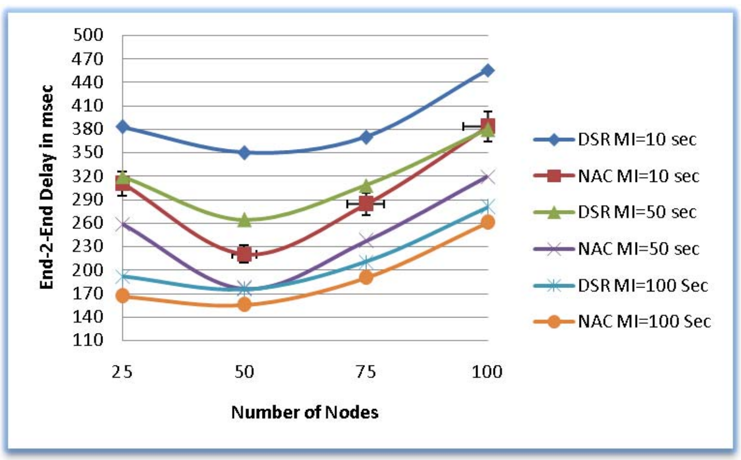


Figure 3: Impact on the network on End-to-End delay

Figure 3 shows that the mobility does not degrade the delay performance, in most of the scenarios, until the number of MTs exceeds 50. However, as the network gets congested with number of nodes, there will be more cluster formation in case of NAC procotol and more flooding message in DSR protocol. Hence, more available paths for a packet to reach its final destination. This will add to more routing delay. Therefore, we see more delay for larger values of MTs.

Figure 4 shows that the delay quality is within the acceptable range till 3 or 4 hops, after 4 hops the performance degrades sharply. As we can see, the probability of mobility of the nodes increases, the number of hops slight drops down, especially in the case of DSR protocol.

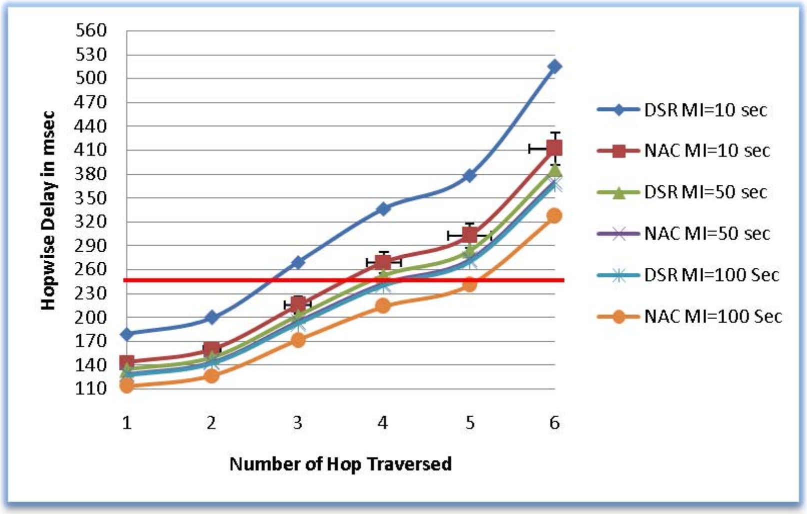


Figure 4: Impact on the network on hopwise delivery

However, the hop count can be increased up to 5 or 6 hops if we relax maximum threshold limit to 400 msec, as it is acceptable in some cases [28]. As we mentioned earlier, the average maximum distance between the mobile terminals is $\Theta(\sqrt{N})$. From figure 5, we can conclude that the average power left on MTs in case of NAC is almost twice than that of DSR protocol. Clearly, this is a direct result of nodes being always active in the DSR protocol. It is important to mention here that we plot power versus nodes normalized by delivered packets. With the increase in MTs, the network connectivity becomes mature and there is more exchange of packets.

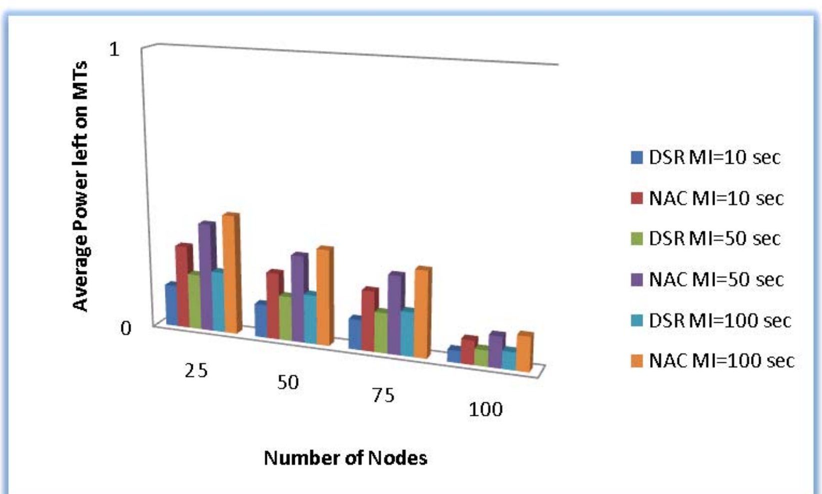


Figure 5: Impact on the network on average remaining power in MTs

In figure 6, we observe that with a few number of nodes the network will be suffering for disconnectivity, especially if they stay far away from each other. This is natural when the network has less than 50 MTs. But, as the number reaches beyond 50, we see the highest output because of maximum connectivity. The output again decreases for larger number of nodes, because the network gets congested with too many packets and other control packets causing queuing (buffering) delay to increase drastically, which results in drop once the delay exceeds the limits for certain packets. Moreover, access to the medium also becomes difficult with such a high number of nodes. Finally, the drop is proportional to the mobility. Hence, we get less successful transmissions when the probability of mobility is high (MI=10). From all the above simulation results, it is interesting to observe that both NAC and DSR protocols have the same behavior, but with different performance.

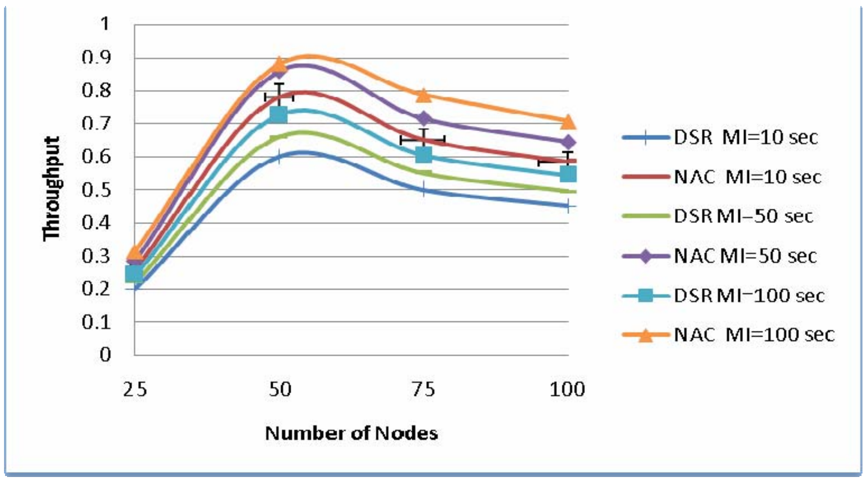


Figure 6: Impact on the network on average throughput

8 Conclusions and Future Work

In this paper, we investigated the feasibility of implementing H. 264 over two routing protocols in ad hoc networks, mainly: the neighbor-aware clusterhead and the dynamic source routing protocols. We found that 2 Mbps is not suitable for video traffic, i.e. distance of 100m. Instead 5.5 Mbps link speed is necessary for acceptable performance. DSR protocol can support up to 3 and 4 hops without any serious degradation in the video quality for high and low motion interval respectively. However, NAC protocol can support 4 and 5 hops for high and low motion interval respectively. After that the performance is seriously deteriorated. A significant amount of power can be saved if HCB model is applied within the neighbor nodes. However, it is not suitable in our application, since it suffers from per hop delay, which will add unnecessarily transmission and medium access delays. Finally, the hop count can be increased to 5 or 6 hops if we relax maximum threshold limit to 400 msec as it is acceptable in some cases [28]. NAC and DSR protocols have similar behaviors in reacting to mobile terminals movement and network topology changes. However, the simulation results revealed that the NAC protocol outperforms the DSR protocol in terms of power conservation, delay performance and successful packet transmission. We plan to research the affect of other different compression scheme on the protocol performance and investigate new techniques to maximize the distance or number of hops to minimized delays.

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