Power Consumption Optimization and Delay Minimization in MANET

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ABSTRACT
The performance of wireless networks under video traffic is subjected to two-fold constraints. Both power minimization and other QoS requirements such as delay, delay jitter etc. need to be taken care of properly. Mobile Ad Hoc Networks (MANETs) are more sensitive to these issues where each mobile device acts like a router and thus, routing delay adds significantly to overall end-to-end delay. In this paper, we analyze the performance of the Warning Energy Aware Clusterhead/Virtual Base Station-On-demand (WEAC/VBS-O) protocol, proposed earlier by one of the authors [1], in terms of average delay, multihop communication and power minimization aspects subject to video traffic. The H.263 standard is utilized to model video traffic in our simulation design. Primarily, we establish a single hop communication between nodes. It is then extended to multihop communication. However, we found that the protocol can support up to two hops for an acceptable network performance provided there is a significant number of nodes in the network. Hence, we modelled the same network with H.264 and showed that the hop count increases from two to five with better performance. We also took power minimization issue into consideration and minimize power consumption by making use of HCB model by applying it within the neighborhood of the node. Simulation results showed that this strategy does minimize power consumption and it did not degrade multihop communication improvement. With the idea that maximum power saving is achieved if the relaying node lies in the middle of source and destination node for HCB model [2]. Furthermore, we saw the effect of sudden demise of cluster heads in the Warning Energy Aware Cluster head (WEAC) protocol based on our previous work [3]. Subsequently, we compared the results when some clusterheads (CHs) have sudden death to the results when there is no switching of CH based on selected performance metrics. We found that there is little power loss if the relaying node is not in the middle of source and destination node. However, performance is seriously degraded on the introduction of sudden demise of CH during simulation as far as average end-to-end delay is concerned.

Categories and Subject Descriptors
B.4.5 Reliability, Testing, Fault Tolerance (Input / Output, Data communication)

General Terms
Algorithms, Performance, Measurements, Experimentation

Keywords
Ad hoc networks, routing protocols, video streaming

1. INTRODUCTION
Along with non-real time data, wireless networks are becoming common for real time services. But, the need for prior infrastructure is still a very common feature and an important requirement in both wired and wireless networks for reasonable performance. On the contrary, MANETs offer infrastructure less base with limited bandwidth, which is not very much suitable to multimedia traffic such as video data. Efforts have been made to use efficient compression techniques to make optimal use of limited bandwidth which result in, of course, more power consumption [4,5]. At the same, there is a maximum tolerable delay and delay jitter requirements for video data. Therefore, numerous MANET algorithms have been proposed aiming at achieving good performance in terms of video quality, throughput, delay and delay jitter [3,6].

The growth of the network directly depends on the number of hops within given constraints (delay, bandwidth, quality, power, etc.) in a typical MANET [7]. This makes the estimation of number of travelled hops, for which the delay does not exceed the maximum tolerable value for video data (<250 msec), a hot research area [8]. Transmission of video over MANET multiplies the sensitivity of these issues to a great extent which has directed researchers to propose a variety of approaches to build a typical MANET [5,9,10,11]. It is worth-noting that more attention is given to energy consumption of each node since the battery (energy) of a mobile device is the main driving source to MANET, especially MANET size is largely dependent on it [12]. Hence, energy issue requires more attention in case of video transport over MANET [12,13,14]. In this paper, simulation is carried to show both single hop and multihop communication in MANETs under video traffic both with H.263 and H.264 compression schemes. We calculate maximum number of travelled hops under tolerable delay constraint (i.e. 250 msec) for video traffic. We show how it is possible to increase hop count without degradation to video quality by making use of a new video standard, i.e. H.264. We also estimate power consumption...
for each node and analyze network performance accordingly. Then, we attempt to minimize power usage by applying HCB model within the neighborhood of each node. Afterwards, we work on analyzing the effect of relay node position on the power savings and we calculate the average deviation from maximum power savings by simulation. Furthermore, one of the important issues in ad hoc routing is sudden switching off clusterheads (CHs) during simulation. D.3.3 []

We also observe this effect in our simulation study and building on it, and show a comparative performance analysis of the WEAC protocol. We compare the results when some CHs have sudden death to the results when there is no switching of CH based on selected performance metrics.

The rest of the paper is organized as follows. In Section 2, we briefly discuss the video standards. Section 3 covers how we applied HCB model within the node-neighborhood (and not to the entire network). It then states the strategy we used to calculate the percentage deviation of maximum power saving, on average. Section 4 provides an overview of our traffic modeling, node mobility model, which is controlled by a parameter motion interval (MI), and delay analysis. In Section 5, we analyze and compare our simulation results obtained based on different performance metrics. Finally, Section 6 presents concluding remarks and proposed future work.

2. H.263 AND H.264 STANDARDS

In this section, we describe both video compression standards, namely: H.263 and H.264.

2.1 H.263 Standard

H.263 is standardized by International Telecommunications Union (ITU) for video data communication in 1995. It performs better for video data where there is little to do with motion such as video conferencing, motionless video communication in MANETs, etc. Thus, it is designed for low bit-rate communications (i.e. wireless networks). It can support five types of resolution (CIF, QCIF, SQCIF, 4CIF, 16CIF) out of which we use Quarter Common Intermediate Format (QCIF). We select QCIF due to its acceptable resolution efficiency and its suitability for our selected bit-rate and frame rate, which provides 56 kbps and 30 fps (frames per second) respectively. Architecturally, it is very similar to its predecessor standard (i.e. H.261) but it carries some enhanced features [15]. For instance, improvements in performance and error recovery have been brought about by using half pixel precision (instead of full) and making hierarchical structure optional. Detailed description of this standard can be found in [15].

2.2 H.264 Standard

It 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 [16]. There are many enhanced and new blocks that have been brought into this standard, such as multi-picture motion compensation with up to 32 reference pictures that can be used and thus allowing improvements in data rate and video quality, variable block size (from 16x16 down to 4x4), quarter pixel precision (precision of 1/8th pixel is possible), deblocking filter (for finer tuning in picture shape), 4x4 linear DCT (before it was real, so computationally easy), NAL (network abstraction layer), Data partitioning, etc. The main goals of this standardization are to provide compression performance and video representation addressing video telephony and non-conversational (storage, broadcast, or streaming) applications suitable for network environment [17]. Finally, H.264 is equally suitable for wireless application, video-on-demand, LAN and mobile networks. Detailed description and analysis of H.264 can be found in [16].

3. POWER

We believe that delay (also delay jitter) should be given the highest priority when dealing with video transport over the wireless network. On the other hand, many researchers [2,18,19,20] have focused and emphasized on saving power of the node battery to last for longer time (without recharging) and a lot of researchers. In this work, we also minimize power to an extent that it does not degrade improved delay performance. We use HCB and RM (named after those who proposed these schemes) models to minimize power within the neighborhood.

4. TRAFFIC MODELING

In this section, we first describe traffic modelling for simulation, followed by an idea of analytical measurement of average end-to-end delay in subsection 4.2. Finally, we describe selected performance metrics after discussing the mobility model in subsection 4.3.

Table 1: Simulation parameters

<table>
<thead>
<tr>
<th>Packet Size</th>
<th>2Kbyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hello Packet Size</td>
<td>1Kbyte</td>
</tr>
<tr>
<td>Other Control Packet Size</td>
<td>100Byte</td>
</tr>
<tr>
<td>Frame Size</td>
<td>176x144(QCIF)</td>
</tr>
<tr>
<td>Bits per Pixel</td>
<td>0.2</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>56kbps</td>
</tr>
<tr>
<td>Link Speed</td>
<td>5.5Mbps</td>
</tr>
<tr>
<td>Medium Access Technique</td>
<td>CSMA/CA</td>
</tr>
<tr>
<td>Maximum Tolerable Delay</td>
<td>250msec</td>
</tr>
<tr>
<td>Initial Transmission Energy/Node</td>
<td>100joules</td>
</tr>
<tr>
<td>Average Codec Power/Packet</td>
<td>500mW</td>
</tr>
<tr>
<td>Average Compression Delay</td>
<td>50-60msec</td>
</tr>
</tbody>
</table>

4.1 Arrival Traffic Specifications

Table 1 shows selected parameters of our simulation design. We used MATLAB to simulate the WEAC protocol for packet level simulation. H.263 standard parameters are used for video traffic simulation. We selected QCIF frame size because of reasonable resolution quality and 56 kbps (low bit-rate) bit streams after compression. Compression ratio is 10:1. This is because H.263 is fit for motionless video conforming to our intuition. Hence, it can compress to such a high ratio. After compression, the bits are packetized into fixed packet size of 2 KB. As mentioned earlier, the data rate is 3.5 packets per seconds (56 kbps). For the sake of comparison between H.263 and H.264, we do not change the intensity of traffic, link speed, number of nodes, etc. We use H.263 and H.264 standard parameters for video modelling. After
compression, the bits are packetized into fixed packet size of 2KB. The data rate is 3.5ppps (56kbps) and 4pps (64.76kbps) for H.263 and H.264 respectively.

The drastic degradation of network performance can be observed in the simulation results after the network is congested (saturation considering no control packets). But before it happens, it is worth-noting that the network is congested even for 50 or 100 nodes. This is because video packets are not the only packets that are being exchanged among the nodes. Instead, hello packets waste most of the link bandwidth because of their large size (1 KB) and frequency of occurrence compared to the actual data packets. In addition to hello packets, there are other control messages such as IamNoLongerYourCH, WarningMessage, MergeAccept and MergeRequest, etc., which also exist in the network and use its resources. Therefore, we suggest after experiment that 2 Mbps is not enough for video traffic and it is incumbent to use a higher data transfer rate (~ 2 Mbps). We have used 5.5 Mbps in our simulation to ensure the feasibility of video traffic over MANETs.

4.2 Delay Modeling

Video data is very sensitive to delay, because in order for the communication to be meaningful the data has to be received before a maximum threshold of delay (250 msec), where the reception of data is of no use. Therefore, special care must be carried out to minimize the delay as much as possible. In our experiment, compression/decompression delay, routing delay, CSMA/CA delay, propagation delay, transmission delay and queuing delay constitute the overall delay. This can be described by the sum of all delays, as:

\[
\text{Total Delay} = \text{Compression Delay} + \text{Decompression Delay} + \text{Queuing Delay} + \text{Propagation Delay} + \text{Transmission Delay} + \text{CSMA/CA Delay} + \text{Routing Delay}.
\]

Where,

\[
\text{Propagation Delay} = \frac{d_h}{\text{Link Speed}}, \text{ where } d_h \text{ is the distance between two nodes or 1-hop distance, and,}
\]

\[
\text{Transmission Delay per Packet} = \frac{\text{Packet Size}}{\text{Link Speed}}
\]

CSMA/CA delay depends on the network environment and varies accordingly, but its average value approximately varies around 0.3 msec for an infinite traffic [22]. To calculate the minimum delay, the minimum CSMA/CA delay is sit to 0.3 msec. Out of these seven delays, propagation delay is negligible and thus can be ignored. In order to have an idea of lower and upper bound, we can also ignore per packet transmission delay, here, as it is negligible when compared with compression/decompression delays that are much larger than it, however, we have taken it into consideration in our simulation program. For H.263, if everything goes well, compression delay should be around 2 frames of the delay [23], i.e. 1000*2/30 = 66.66 msec. There are only two types of delay (routing and queuing) that vary significantly and both of them 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 60-80 msec, then an approximate minimum value of total delay is equal to 90.3 (80+0.3+10) msec.

Where 10 msec is represents the total value for routing and other types of delays. For acceptable performance, this gives a lower bound and implies that the delay should vary according to the following relation:

\[
90 \leq \text{TotalDelay} \leq 250
\]

There is another approach which deals with an approximate value of average delay per packet (instead of delay interval). We know that there is no compression/decompression delay at intermediate nodes. Therefore, only processing and CSMA/CA delay add to the overall average delay at intermediate nodes which is approximately 6 msec in our case and we denote it by DI. We can intuitively approximate the delay, where each packet is supposed to undergo by the following relation [24]:

\[
\text{Delay} = \frac{1}{\text{Link Speed}} \left( \text{PktSize} \cdot N_{\text{rt}}^{\text{nt}} \cdot n_h + D_h \right),
\]

where, \(N_{\text{rt}}^{\text{nt}}\) shows the number of retransmissions per packet and \(n_h\) is the number of hops traveled. Since there is seldom need of retransmission for video packets, it (retransmission variable) is zero in most of the cases. We will provide more discussion on these two delays in the results section and verify our proposed analytical equations.

4.3 Mobility Model

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 velocity of 5 km/h after a short interval (controllable). We can change the mobility effect by changing this interval. For instance, if the motion interval (MI) is 30 means the nodes move with 5 km/h after every 30 sec. If MI is reduced to 10, then the frequency of the motion increases (i.e. after every 10 sec the node moves). Thus, decreasing the interval yields too many disconnections which results in more drop in the network and vice versa.

4.4 Performance Metrics

We simulated a typical MANET for hop and power consumption calculation with some assumptions. The delay constituents are compression, transmission, propagation, routing and CSMA/CA delay for medium access. As the receiver power is negligible compared to transmission power, so we ignore it in our simulation. Table 1 lists some of the values used in our simulation as per two selected video standards. We also assumed that the maximum coverage area never exceeds 2000 meters on each side. We concentrated on the following metrics:

- **Delay**: End-to-end delay (Delay) is the time taken for a packet to be transmitted across a network from source to the destination. More precisely, it is the time required for a packet to reach its final destination from the time when it is generated. We plotted average end to end delay versus number of nodes and versus frame size, but we changed only one parameter for a single run. In order to see the maximum
number of supported hops, we drew hopwise 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 (MI) to 100, 60, 30, 10 seconds respectively.

- Successful Transmission Percentage: It is insignificant to look at delivered packets percentage to analyze the network performance. Therefore, we normalized delivered packets with sent packet.
- Delay Jitter: The inter-arrival time of a packet at the receiver is not constant, fluctuates. Delay jitter is a measure of the difference between 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.

5. SIMULATION RESULTS AND ANALYSIS

This section provides discussions on the achieved results from our simulation model. This includes delay, Successful Transmissions and delay jitter.

5.1 Delay

Delay is perhaps the most important parameter to be considered for video traffic. Figure 1 shows the variation in average delay as we increase the number of nodes. It varies approximately between 100 and 270 msec, which is almost within the acceptable range (i.e., 250 msec). Moreover, we also show the increase in delay due to node mobility. We can easily see from Figure 3 that the greater the mobility, the higher the delay and vice versa. It is interesting to note from Figure 1 that the mobility does not degrade the delay performance until N exceeds 30 nodes. This is because there are a few clusters with less number of available routes for some packets to reach their destination. This results into either less routing delay or more packet drop. This makes it difficult to predict the behavior of the network before reasonable connectivity. Sometimes there is less routing delay if the packet obtains desired connectivity, but at times the failure to desired connectivity results in packet drop and hence larger overall delay. For instance, in Figure 3 the delay for MI = 60 is larger than that for MI = 10. However, as the network gets congested with number of nodes, there will be more cluster formation and 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 N.

Delay is perhaps the most important parameter to be taken care of in case of multimedia traffic (voice/video, etc). Figure 1 shows the average delay (normalized by received packets) with the increase in node-numbers. We can see drastic increase with H.263 in the delay after the number of nodes goes beyond 100, whereas the delay is relatively less with H.264. This is due to less compression delay of H.264 scheme which uses simple wavelets scheme for data representation and 4x4 integer transform. Moreover, if we compare these results with the results presented in [14] we draw more insights to the delay improvement obtained by H.264.

Figure 2 highlights hopwise delay versus number of hops traveled. We can observe that the delay quality is within the acceptable range till two hops after which it degrades sharply. Therefore, the WEAC protocol can support up to two hops for a video traffic that is compressed using H.263 standard. In addition, as the mobility of the nodes increases, the number of hops slight drops down to 1.5, i.e. 1-hop. However, the hop count can be increased to 3 or 4 hops if we relax maximum threshold limit to 400 msec as it is acceptable in certain circumstances [23]. Lastly, we also note that the maximum traveled hops during simulation approximately equal to $\sqrt{N}/2$ for most of the values of N. This observation validates the hypothetical model presented in [24]. A comparison between H.263 and H.264 schemes using hopwise average delay and travelled hops is shown in Figure 2. In our earlier work [21], we showed that the supported number of hops by H.263 over WEAC protocol up to 2. We noticed that H.264 can extend traveled hops to 4 without any degradation in the quality of the received data.
All is being achieved due to the elegance, simplicity and efficient scheme of the new codec H.264. It is interesting to point out that we did check these simulation values of hopwise delay with those obtained using the following expression, where little differences was observed.

\[
\text{Delay} = \frac{1}{\text{LinkSpeed}} (\text{PktSize} \times N_{\text{all}}^{\text{out}} n_g + (n_g - 1) D_t)
\]

Next, the effect of sudden demise of CH was observed on overall average delay. The end-to-delay performance is deeply influenced by the sudden (probability based) demise of CH(s). Figure 4 shows the deterioration in performance of the network as compared to the results shown in Figure 3.

The performance keeps on deteriorating as N increases because the network is highly connected with large N. Thus, switching off a single CH means far many disconnections in the network and network takes time to regain its stable connectivity which results in increase in the delay to a great extent as shown in Figure 5. In addition, the sudden demise of CH is also responsible for extra overhead of control packets that are communicated among the nodes in search for a new eligible CH.

5.2 Successful Transmissions

In 2×2 square km area, high dis-connectivity is obvious when the number of nodes is less than 30 or so especially if they stay far away from each other. This behavior has been shown in Figure 5 for nodes less than 40. We observe the highest output as the number of nodes exceeds 40, because of maximum connectivity. The output again decreases for larger number of nodes because the network gets congested with too many hello and other control packets. This causing queuing (buffering) delay to increase drastically, which results in drop once the delay exceeds the limits for certain packets. Access to the medium also becomes difficult with such a large number of nodes. Moreover, the drop is proportional to the mobility. Hence, we get less successful transmissions when the mobility is high (MI = 10). Lastly, Figure 5 shows the effect of sudden demise of CH(s) on overall successful transmissions. We can see very clearly that this effect further deteriorates the performance and this percentage keeps on decreasing as explained earlier.
5.3 Delay Jitter

Delay jitter is an important parameter to judge QoS of the network performance. Figure 6 shows the variation in delay jitter with the increase in number of nodes. The jitter almost remains constant after some transient period where the nodes are not enough and their small number is the major cause of network disconnectivity.

It is acceptable ($\leq 150$ msec) for low mobility (MI = 100 and 60), but increases beyond the limit for high mobility. It is even acceptable if we compromise a little on the video quality which normally happens in wireless networks.

6. CONCLUSIONS AND FUTURE WORK

We have shown in this paper the WEAC protocol performance subject to video traffic. We also derived a number of interesting results. Firstly, we found that 2 Mbps is not suitable for video traffic. Instead, 5.5 Mbps link speed is necessary for acceptable performance. Secondly, this protocol could support up to 3 hops without any serious degradation in the video quality. Thirdly, we could save significant amount of power if we apply HCB model within the neighborhood of a given neighbor. Finally, the hop count could be increased to 3 or 4 hops if we relax maximum threshold limit to 400 msec. We have also shown the power saving loss due to the deviation from maximum power savings and the effect of random (probabilistic) demise of CHs for the WEAC protocol based MANET. In addition, the effect of CH demise badly deteriorates the protocol performance in terms of delay and other chosen performance metrics. The metric, Average number of CHs, shows the reduction in CH number which implies that either there are more number of free MTs in the network due to the none availability of proper CH in their neighborhood or there are more number of zone MTs per CH; thus, increasing overhead per CH. Both of these two scenarios yield poor connectivity, extensive increase in the average delay and fast discharge of the battery of the nodes. Furthermore, we have also shown comparative study between H.263 and H.264. The WEAC protocol is suitable for video traffic when used with efficient compression scheme such as H.264. The immense compression delay reduces the number of hops dramatically in case of H.263. The simulation results showed that H.264 outperforms H.263 in end-to-end delay, power consumption and number of hops. It is in agreement with [16] that H.264 should be regarded as the video coding option for the next generation of multimedia.

We intend to see the affect of different compression scheme on the protocol performance. H.264 may be the best choice for wireless networks. We intend to work on some suitable solution to this sudden demise of CH. For example, some machine learning techniques like reinforcement learning [25] could be used to nullify this problem. These two directions may be the focus of our future research. We also intend to use parameters such as data rate specification, etc. discussed in [26]. We expect to get higher hop count with those specifications.

Acknowledgment

The authors would like to thank King Fahd University of Petroleum & Minerals (KFUPM) for their support with which the project number IN070377 was carried out successfully. The authors would also like to thank Acadia University for its support. Special thanks go to COMSATS Institute of Information Technology (CIIT), Lahore for their encouragement toward research work.

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