VIDEO TRANSPORT OVER MULTI HOP DIRECTIONAL WIRELESS NETWORKS

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ABSTRACT

Exploiting directional antenna technology in wireless networks has become an attractive option because of the potential capacity increase through spatial reuse. Such development apparently has profound impact to wireless multimedia applications. While the advantages of directional transmission in single hop networks (e.g. WLANs and cellular systems) have been evident, it has also been recognized that multi hop directional networks may suffer long transmission delays and frequent link breakages if conventional routing protocols (e.g. AODV and DSR) are used. This is mainly due to the unique feature of directional transmission commonly known as "node deafness". To address this problem, we propose a multi-path routing scheme which focuses more on minimizing per-hop delays instead of traditional route length. We further propose a differentiated service (DiffServ) framework for layered video transport over multi hop directional network using QoS aware multi-path routing as well as class based queuing (CBQ). Both network layer and application layer simulation results are presented to demonstrate the effectiveness of the proposed video transport scheme over directional networks.

1. INTRODUCTION

Recently there have been growing research interests in applying directional antenna to multi hop wireless networks (or ad hoc networks). Traditionally mobile devices are equipped with omnidirectional antennas, which transmit and receive RF signals in all directions with equal antenna gain. Because of the shared media property of wireless channel, while one node is transmitting, all the other nodes within the transmission range will have to remain silent until the transmission is completed. This conservative MAC scheme, known as collision avoidance (CA), obviously causes some inefficiency in network resource utilization. Unlike an omnidirectional antenna, a directional antenna can focus its RF transmission and receiving in one of its antenna elements. If an adjacent node does not lie in the active antenna element of a busy node, it can transmit or receive signals without interfering with the existing transmission. Conceptually, applying directional antenna to multi hop wireless networks can effectively increase channel capacity. Furthermore, according to half-wavelength element spacing, an eight-element cylindrical array will have a radius of 8 cm at 2.4 GHz, 3.3 cm at 5 GHz and 0.8 cm at 24GHz [1]. Such small dimensions make it possible to equip hand-held mobile devices with antenna arrays, and to exploit this technology in multi-hop wireless networks.

A directional antenna has a conical radiation pattern with a spanning angle of $\frac{2\pi}{N}$ radian. In a "switched beam" antenna model, the radiation pattern partitions the propagation plane into N non-overlapping sectors. Each sector is considered to be covered by an antenna element. Transmission in one sector will not affect signal propagation in other sectors. Therefore a spatial region previously occupied by one omnidirectional transmission may now be shared by multiple directional transmissions. This property is commonly known as "spatial reuse". Other advantages of directional antennas include low probability of detection, robustness to jamming, and lower energy consumption at the same transmission range.

Although directional antennas have the potential to increase network capacity as suggested by "spatial reuse", recent studies have not been able to observe such performance improvement at network level in multi hop environment [2]. A very fundamental problem is caused by the fact that directional antenna can only communicate over one or a few elements at a given time, which makes a node temporary "deaf" and invisible on all the other directions. This temporary deafness will cause unstable routing behaviors because any discovered route can be easily broken if one of the nodes along this route is steering to a different direction. Traditional routing protocols will respond to this situation with an expensive and unnecessary route recovery process, which may generate large amounts of routing overhead and degrade the network performance.

In this work, we present a multi path routing scheme that can effectively realize the advantage of spatial reuse and achieve significant system capacity improvement. Our approach is to discover multiple paths for each pair of source and destination, so that when a node on the route is temporarily unavailable (i.e. deaf), an alternative route can be selected immediately, and no route rediscovery will be initiated. The deaf node will soon appear back online once it finishes a directional session. This approach aims at minimizing per-hop delay instead of minimizing the overall route length. The new routing scheme is implemented based on a popular ad hoc routing protocol, namely Dynamic Source Routing (DSR) [3].

We further propose a differentiated service (DiffServ) framework [4] for video transport over multi hop directional networks [5]. It takes advantages of several components including multi path directional routing, class based queuing (CBQ), and scalable (or layered) video source coding. A popular scalable video coder, 3D-SPIHT [6], is used to generate multi-layer video streams. The coded bitstreams are segmented into multiple layers, each with a different level of importance. The multi-path routing protocol will label each discovered route with a link metric which indicates its quality of service (QoS) characteristics. The video layers will be distributed among these paths according to their QoS priorities. This scheme is referred to as "QoS aware multipath routing". CBQ is also implemented at all intermediate nodes, which gives preference to important layers in packet forwarding. Through this approach, the overall performance measured by the end-to-end video transport quality will be effectively improved.

2. ANTENNA MODEL AND MAC PROTOCOL

The antenna model in our study consists of N beam patterns as aforementioned. The antenna can operate in two modes: omnidirectional and directional. In directional mode, only one beam can be used at one time with a gain of G_d, and in Omnidirectional mode, signals are received with a gain of G_o. G_d is inverse proportional to the number of beams used. The transmission distance of the antenna is proportional to the transmission gain. So, a directional transmitters can reach longer distance than an omnidirectional transmitters at the same transmission power.

Most of the common ad hoc MAC protocols are based on IEEE 802.11 Distributed Coordinated Function (DCF). DCF requires an exchange of Request-To-Send (RTS) and Clear-To-Send (CTS) messages before each data communication. Both RTS and CTS packets contain the duration for the request data packet transmission. Other nodes located in the vicinity of the communicating nodes must defer their channel access according to the specified duration. This process is called "virtual carrier sensing".

Applying IEEE 802.11 DCF to ad hoc networks with directional antennas limits the spatial reuse capacity, because the RTS and CTS handshake is assumed to be sent omni-directionally. In our implementation, a directional antennal Medium Access Control protocol (DiMAC) [2] is used as the MAC protocol. DiMAC is based on IEEE 802.11 DCF, except that RTS/CTS are sent by directional antennas where the beam should be specified.

3. DELAY-SENSITIVE MULTI-PATH ROUTING SCHEME

The major challenge of conventional ad hoc networks has been considered as mobility, because it introduces frequent topology changes that is not seen in wired networks. The deafness of active nodes further increases the dynamics of instantaneous topology of an ad hoc network. Its impact is even greater than that of mobility, because switching from one antenna element to another can be very fast, and the duration of each data exchange session is highly unpredictable. This requires a fundamental revision of existing MAC and routing protocols.

To address this problem, we propose a delay-sensitive multipath routing scheme that can exploit spatial diversity to cope with temporary channel blockage caused by deafness. This scheme involves several modifications to the conventional MAC and routing protocols. For example, it will reduce the number of MAC retransmission when there is an un-acknowledged transmission, and it will keep a temporarily non-responding node in the routing tables. Most importantly, this scheme will obtain multiple paths to each destination. When a temporary link blockage occurs, an alternative route will be selected to forward the packet immediately. This approach can reduce the delay caused by retransmissions or waiting for the next node to become available again. Multipath routing has been frequently proposed for traffic balancing and capacity improvement in conventional ad hoc networks. It becomes a more attractive option in directional ad hoc network because spatial reuse effectively partitions a local channel into multiple subchannels, and alternative routes become easier to find.

Our multipath routing scheme shifts the focus of routing design from route length sensitive to per-hop delay sensitive. This is based on the assumptions that **1)** a link blockage is more likely to be caused by node deafness than node motion; **2)** the chance of finding multiple routes is higher in directional ad hoc network; and **3)** taking an alternative route will not have significant performance penalty (e.g. through excessively long routes) because of directional transmission.

3.1. Routing Protocols

DSR [3] uses source routing method in which the sender specifies the complete hop-by-hop route from the source to the destination. When a node needs a new route to a destination, a route discovery will be initiated, during which the source node broadcasts a route request (RREQ) into the network. Each node receiving an RREQ message will check its destination. If the node is the destination, or it has a route to the destination in its route cache, it will respond the sender with a route reply (RREP) message. Otherwise, it will add its address to the "route record" in the RREQ and further broadcast it into the network. An intermediate node will only broadcast an RREQ if it is received for the first time. Once an RREP is generated, it will be routed back to the source by traversing the path in the RREQ's route record. This route record is then stored in source route cache.

DSR itself supports multi-path routing, since each node will store multiple overheard routes in its routing cache. The problem is that most of the routes to a certain destination are overlapped with each other, which makes them less useful. To increase route diversity, an intermediate node can forward the same route request more than once if it comes from a different sender and it has a same or shorter length. This will certainly generate more routing packets to the network, but the benefit of this approach is that the intermediate nodes can learn and obtain more non-overlapping routes. We refer to the resulting protocol as "multi-path directional DSR" (MDSR) protocol.

In the packet forwarding process of MDSR, each node delivers the packet to the next hop according to the source route in the packet header. If this attempt fails, it is assumed that there is a collision and will try two more times. If these attempts all fail, it is assumed that this neighbor node is in a "deaf" state and an alternative route is used immediately if it exists. If an alternative route is not available or it is much more costly than the original route, the node keeps trying the original route until it assumes this link is broken. A scan function of the neighbor table is performed to locate this neighbor node in adjacent antenna elements. If the scan process fails, a broken link is assumed and the node will perform a routing update procedure.

3.2. Simulation Results on Routing Performance

The simulation is conducted on Network Simulator (ns-2). At the MAC layer, we implement a directional version MAC based on IEEE 802.11, which include directional RTS/CTS handshake, antenna element neighbor table and the sweep broadcast functions. At the network layer, a MDSR module based on DSR is implemented with multiple paths in the routing table. A fixed 64-packet send buffer is maintained at each node for the packets waiting for available routes. All traffics in the network are set to have continuous bit-rate (CBR) patterns. The source/destination pairs are selected randomly from the entire nodes set, and for each flow the transmission rate is four packets per second with packet size of 512 bytes. The number of flows are varied to provide different traffic load scenarios. To simulate the node movements, we assume the

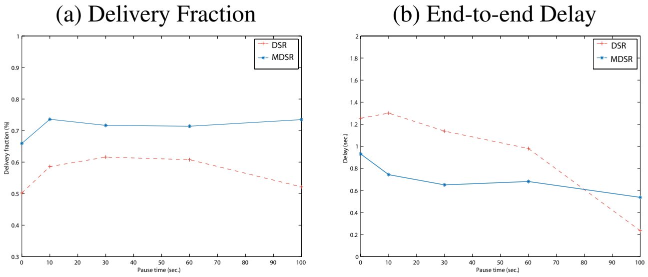

Fig. 1. Performance comparisons of two routing protocols in directional ad hoc network.

random waypoint mobility model in a rectangular field with a dimension of 2500×600 square meters. Fifty mobile nodes are simulated in the network and their initial locations are assigned randomly at the beginning of the simulation. The transmission range is set to be 250 m and the maxspeed of each mobile node is set to be 5 m/s, then the average speed for each node is around 2.5 m/s. The total simulation time for all nodes is 100 seconds and each source node chooses its starting time for sending packets from the range of [0, *stime*]. *stime* is set to be 30 seconds in the simulation. The simulation is based on a six-element antenna system. To compare the results in a fair manner, identical traffic and mobility scenarios are applied to each protocol and each data point in the result graphs are an average of ten simulation runs.

Tow metrics are used to assess the routing performance, namely

1) Delivery fraction (DF) is the ratio of the number of received packets to the number of packets generated by the source node.

2) End-to-end packet delay is calculated only based on the successful transferred packets.

The performance curves in Fig. 1 (a) and (b) represent *DSR* and *MDSR*. In most cases, *MDSR* achieve better performance than *DSR* in terms of delivery fraction and delay in directional networks. Only exception is the end-to-end delay at very low network mobility, which is because of unnecessary multipath routing overhead.

4. DIFFERENTIATED SERVICE FOR VIDEO TRANSPORT

In a traditional data network, all packets are treated as equal entities. However it has been recognized that this does not reflect the reality of multimedia networking. Different segments of a video stream may have different contributions to the final video reconstruction quality. Therefore, under a certain network resource constraint, it is desirable to provide higher level of QoS to more important data segments, and vice versa. This approach is known as "service differentiation" [5].

The proposed DiffServ video transport scheme incorporates three major components. A QoS aware multipath directional routing protocol based on MDSR, a class based queuing mechanism, and a scalable 3-D wavelet video coder, 3D-SPIHT.

4.1. Link Metrics

In the aforementioned MDSR protocol, the source node normally receives multiple route replies to one route request. To introduce "QoS awareness", each replied route is labeled with a link metric that indicates the traffic load or service quality along this route. A set of link metrics are collected at each intermediate node, and aggregated during route discover process. Multiple paths with different link metrics provide a nature framework for service differentiation within a coded video stream. More specifically, important layers of the video stream will be routed through paths with high quality metrics, and vice versa.

Routing choice is based on an aggregation of three metrics in the proposed video transport scheme. They are contention information from MAC layer, number of packets in the local interface queue, and number of hops along the route.

The channel contention situation is represented by the channel busy and idle ratio, which is calculated at the MAC layer of each node once per second. Let C_{NAV} denotes the ratio of the current second and A_{NAV} denotes the average ratio, the value of A_{NAV} is updated according to

$$A_{NAV} = \alpha \times C_{NAV} + (1 - \alpha) \times A_{NAV},$$

where α is a pre-defined constant and is set to 0.1 in our simulation.

The number of packets in local interface queue is a metric representing the traffic pattern of this very node. The average queue size is calculated upon receiving each incoming packet and is updated according to the following formula:

$$A_{qlen} = \beta \times C_{qlen} + (1 - \beta) \times A_{qlen},$$

where A_{qlen} denotes the average queue length and C_{qlen} denotes the current queue length, and β is constant and is set to 0.1 in the simulations.

Finally, the number of hops N_{hop} is also used as a metric.

The aggregated link metric is then defined as:

$$A_{agg} = w_1 \times A_{NAV} + w_2 \times A_{qlen} + w_3 \times N_{hop},$$

where w_1, w_2, w_3 are weights of different metrics, and they are empirically set to 3, 0.2, and 1 respectively in our work.

4.2. Class Based Queuing

Although QoS aware multipath routing can provide differentiated services to different video steam segments, the actual service quality of each link can not be controlled by the video transport system because of random background traffics. To ensure certain QoS for most important segments, a class based queuing (CBQ) mechanism is introduced to preferentially forward layers of video streams according to their importance levels.

At each intermediate node, class based queuing can dynamically partition the queue space into several sub-queues, each of which is assigned to a particular importance class. When a single class traffic is present, the whole queue is allocated for this traffic. However when traffics from more than one class are passing through, the queue space is partitioned and a sub-queue is allocated to each of these classes. The queue partition occurs when the node receives the first packet from a different traffic class. Priority queuing scheme can then be applied. When channel is available, the packets in higher priority queues will be transmitted at higher probabilities than those in lower priority queues.

4.3. Simulation Results on DiffServ Video Transport

In this simulation, fifty mobile nodes are located inside a rectangular region of $1800 \times 1200 m^2$, and they are initially set at least 200 meters apart. Each mobile node has a continuous and random motion with a maximum speed of 1 meter/second. The shared radio media has a nominal bit rate of 2 Mbps, and radio range of 250 meters. The video streams are transmitted as *ns*-2 CBR traffic

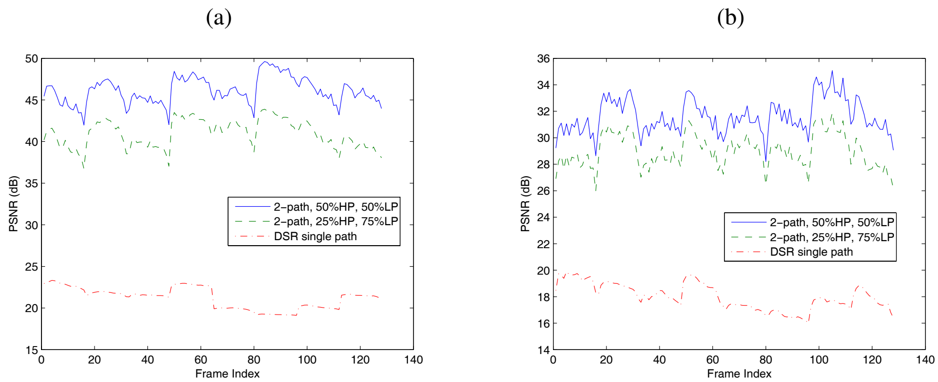

Fig. 2. PSNR performance of multipath video transport over directional ad hoc networks. (a) AKIYO sequence. (b) FOREMAN sequence.

with a total bit rate of 192 Kb/s. Small packets with size of 96 bytes are used for real-time streaming. UDP is used as transport protocol. Ten (10) to sixteen (16) UDP traffic flows are introduced as background traffics in various settings. Each of these flows has a bit rate of 16384 b/s. The source, destination and the duration of these background flows are set randomly.

The multipath routing is based on MDSR implementation, and CBQ with priority queuing is implemented in the form of "interface queue" for *ns*-2 ad hoc module. Each of the intermediate node has a queue size of 20 packets. In the simulations, a queue space partition produces two 10-packet queues for two different classes. A simple priority queuing scheme is use, which allows the high priority queue to be emptied before any packet to be sent in the low priority queue. This approach can be easily modified depending on the requirements of applications.

The 3D-SPIHT video stream is segmented into two layers based on the quality resolutions. One is labeled as high priority (HP), and one is labeled as low priority (LP). Two different segmentation patterns are tested, one with 25% HP (48 Kb/s) and 75% LP (144 Kb/s), and the other with 50% HP (96 Kb/s) and 50% LP (96 Kb/s). Two paths are selected by the QoS aware route discovery, the path with the minimum link metric value will be assigned to the HP layer, and the path with the second minimum link metric value will be assigned to the LP layer. The performance of these multipath traffics is compared with the performance of a single stream of 192 Kb/s routed by the traditional DSR under the same topology and background traffic environment.

The test video sequences are AKIYO and FOREMAN in QCIF resolution (176, 15 frames/sec). A total of 128 frames are coded at 192 Kbps or 0.5050 bits/pixel (bpp). Every 16 frames are grouped together in the subband coding.

A simple and effective error control mechanism is used for the embedded video streams. The decoder will stop decoding process if it reaches the first packet loss.

Figure 2 shows the simulation results. Each value represents the average result of 50 trials under the same network and traffic condition. From these results we can see that the increase of end-to-end video quality is not linear to the usage of high priority class. More specifically, the (25% HP with 75% LP) setting produces a significant PSNR increase over normal single stream video transport. Further increase of HP usage appears to be less effective.

5. CONCLUSION

This paper presents a study on network performance of multi hop wireless networks using directional antenna technology. A multi-path routing scheme is introduced to address the node deafness problem, which emphasizes on minimizing per hop delay instead of route length. A DiffServ framework is proposed to incorporate QoS aware multi-path routing, class based queuing and scalable video coding to support video communication over directional networks. Simulation results indicate that 1) with proper design of MAC and routing protocols, directional antenna can improve ad hoc network performance in most situations; 2) DiffServ is a viable solution for video communication over directional networks. Although only a 3-D wavelet video coder is discussed and tested, this video transport scheme can be applied to any layered video coding techniques, including MPEG-4, H.263 and H.264.

6. REFERENCES

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