Multipath Unicast and Multicast Video Communication over Wireless Ad Hoc Networks

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Abstract

In this paper, we address the problem of real-time video communication over wireless ad hoc networks. For the unicast case, we propose a robust multipath source routing protocol for both interactive and video on-demand applications. Simulations show that our proposed scheme enhances the quality of video applications as compared to existing protocols. For the multicast case, we propose multiple tree multicast streaming as a way to provide robustness for video multicast applications. Specifically, we propose a distributed double disjoint tree multicast routing protocol called Serial MDTMR, and characterize its performance via simulations. We show that Serial MDTMR achieves reasonable tree connectivity while maintaining disjointness of two trees, and that it outperforms single tree multicast communication.

1. Introduction

A wireless ad hoc network is a collection of wireless mobile nodes that dynamically form a temporary network without an infrastructure. With the increase in the bandwidth of wireless channels, and in the computing power of mobile devices, video applications are expected to become available in wireless ad hoc networks in a near future.

However, there are many challenges for supporting video communication over wireless ad hoc networks. Due to the mobility of wireless nodes, the topology of ad hoc network may change frequently. Thus the established connection routes between senders and receivers are likely to be broken during video transmission, causing interruptions, freezes, or jerkiness in the received video signal. Another factor that influences the quality is high random packet loss due to multi-hop wireless links.

In this paper, we introduce new path diversity schemes to provide robustness for both unicast and multicast video communication applications over wireless ad hoc networks. In the unicast case, we have proposed a routing scheme called Robust Multipath Source Routing protocol (RMPSR) to support multipath video communication over wireless ad hoc networks [19]. We compare the performance of multipath video transmission with RMPSR with that of video transmission with other routing protocols for both interactive video and video on-demand applications.

Multicast is an essential technology for many applications, such as group video conferencing and video distribution, and results in bandwidth savings as compared to multiple unicast sessions. To the best of our knowledge, multicast video communication over wireless ad hoc networks has not been studied extensively. In this paper, we propose multiple tree video multicast communication to provide robustness for video multicast applications. Specifically, we propose Serial Multiple Disjoint Trees Multicast Routing protocol (Serial MDTMR) as a way to build two disjoint multicast trees in a distributed fashion, and characterize its performance via simulations. We show that Serial MDTMR achieves reasonable tree connectivity while maintaining disjointness of two trees. Simulations also show that Serial MDTMR outperforms single tree multicast communication.

The rest of this paper is organized as follows. In Section II, we introduce related work. In Section III, we present RMPSR for unicast communication and characterize its performance via NS simulation. In Section IV, we introduce an approach for multiple tree multicast streaming and verify its performance via simulations. Finally we conclude with discussions and future directions in Section V.

2. Related work

Video transport over wireless ad hoc networks with path diversity has been studied in [1-3]. These approaches mainly focus on how to distribute the video traffic among multiple paths. Layered video coding combined with a selective ARQ scheme was proposed in [1], in which base layer and enhancement layer packets are transmitted over different paths, and only base layer packets are retransmitted. In [2], multiple description coding is used to distribute video traffic over multiple paths.

Video transport over wired networks with path diversity has been well studied in [4][5]. In [4], a framework for simultaneous streaming of video from multiple mirror sites to a single receiver is proposed. In [5], A rate allocation scheme with FEC is proposed for path diversity based video streaming on the Internet. These approaches can also be extended to a wireless ad hoc network scenario.

Recently several multipath routing protocols for wireless ad hoc networks have been proposed [6-8]. Dynamic Source Routing (DSR) [6] is an on-demand source routing protocol, where the packet carries the end-to-end path information in its header. DSR obtains multiple paths for the communication pair, but because duplicate copies of RREQ packets at intermediate nodes are discarded, those paths are highly correlated [7][8], and hence are not suitable for multipath video streaming. Split Multipath Routing (SMR) is one of the best known multipath extensions to DSR [7][9]. It uses a modified RREQ packets flooding scheme in the process of route query. The destination node returns the shortest path and another path that is most disjoint with the shortest path to the source node. Two multipath extensions of DSR are proposed in [10]. Several path selection criteria for building multiple paths are proposed in [8].

There has been a large amount of prior work in the area of multicast routing in wireless ad hoc networks [11-17]. The On-Demand Multicast Routing Protocol (ODMRP) [11] periodically floods the network with control packets to create and maintain the forwarding state of each node. It takes advantage of the broadcast nature of the wireless network by its forwarding group flooding, which provides a certain amount of diversity. The Adaptive Demand-Driven Multicast Routing (ADMR) [13] attempts to reduce as much as possible non-on-demand components within the protocol. ADMR uses no periodic network-wide floods of control packets, periodic neighbor sensing, or periodic routing table exchanges. In ADMR, forwarding state is specific to each sender rather than being shared by the entire multicast group. This approach reduces unnecessary forwarding data redundancy. There is also a local subtree repair scheme to detect broken link by downstream node in ADMR. The Adaptive Core Multicast Routing Protocol (ACMRP) [14] is an on-demand core-based multicast routing protocol that is based on a multicast mesh. A multicast mesh is created and maintained by the periodic flooding of the adaptive core. A core emerges on demand and changes adaptively according to the current network toplogy. This scheme outperforms ODMRP in multi-sources scenarios. The Independent-Tree Ad Hoc Multicast Routing (ITAMAR) [18] creates multiple multicast trees simultaneously based on different metrics in a centric way. ITAMAR constructs multiple edge disjoint or nearly disjoint trees. The main objective of this protocol is to improve the average time between multicast trees failures. The algorithms are basically based on Dijkstra SPF algorithm, which is a centralized approach, and requires knowledge of network topology. One possible problem of ITAMAR is that routing overhead might be very large to get enough information of the network to build multiple trees, and the authors only show how ITAMAR works based on perfect network information.

3. Multipath unicast video communication over wireless ad hoc networks

3.1. Robust multipath source routing protocol (RMPSR)

RMPSR is a multipath extension to DSR, which utilizes desirable features of other multipath routing approaches, and applies several new rules to address requirements of video communication applications. To describe RMPSR, we need to introduce two definitions first.

1. Two routes are nearly disjoint, if the ratio of the number of shared nodes to the number of the nodes of the shorter route is smaller than a threshold value.

2. A route set consists of one primary route and several alternative routes. The primary route connects the source node and the destination node; alternative routes connect intermediate nodes and the destination node. An alternative route and the corresponding subroute of the primary route, which connects the same starting node of the alternative route to the receiver, are required to be nearly disjoint. Two route sets are nearly disjoint, if corresponding primary routes are nearly disjoint.

To provide robustness for video applications, RMPSR builds and maintains multiple nearly disjoint route sets for the video communication almost all the time. A more detailed description of the RMPSR is provided in [19]. We summarize three new features of RMPSR which are most related to video streaming here.

1. When the transmission route is broken, alternative routes in the same route set are used to salvage midway packets. Unlike traditional salvaging schemes, rather than transmitting new packets, alternative routes are only used for salvaging ongoing packets. The reason is that routes in the same route set are correlated, so if the primary route is broken, it is likely that alternative routes have been broken or will be broken shortly.

Thus in order to avoid further loss of future packets, the transmission is switched to another primary route as soon as the transmitting primary route is broken.

2. RMPSR triggers new route request process before the connectivity is entirely lost in order to reduce the number of temporary network outages during the transmission. In our implementation, the protocol triggers new route request process when there is only one primary route left in the route cache of the sender.

3. Similar to other multipath extensions, RMPSR increases the probability of discovering multiple disjoint routes at the expense of an increase in control overhead. To alleviate the impact of routing overhead on the network, both RMPSR and DSR are deployed at each node with different classes of traffic being handled by different routing protocols. Video traffic is given higher priority using RMRSR, while other traffic is given lower priority using DSR. This scheme helps to lower the overall routing overhead, and to maintain high quality of video applications when the amount of other data traffic in the network increases.

3.2. Performance evaluation for interactive video applications

In this section, we test performance of interactive video applications with MDC using RMPSR.

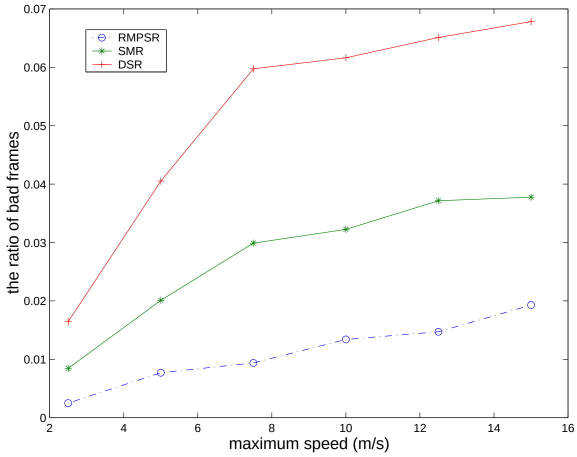
We compare the following three schemes for interactive video applications with MDC. (a) DSR [6] with single path video transmission; (b) SMR [7] with multipath video transmission; (c) RMPSR with multipath video transmission. We use a simulation model based on NS-2 [20] with CMU wireless extension [21]. The random waypoint model [21] is used to model mobility. A 60 nodes network in a 1200 meters by 800 meters rectangular region is used. The bit rate of video is 192 kilobits per second (kbps), and the frame rate is 12 frames per second (fps). Each frame consists of two 8 kilobits packets, each one representing one description. The playback deadline of each packet is 100 milliseconds (ms) after it is generated. If both packets of a frame are received before their deadlines, the frame is called a good one. If only one packet is received on time, the frame is called an acceptable one. Otherwise, it is called a bad frame. Simulations are run for ten hours. There are five random 12 kbps cross sessions in the network. We only consider the continuous mobility case. To change the mobility level of the network, we vary the maximum speed from 2.5 m/s to 15 m/s.

The ratio of the number of bad frames over the number of all frames is shown in Figure 1(a), and the number of bad periods, consisting of contiguous bad frames, is shown in Figure 1(b). The smaller the two metrics are, the better the video experience. As shown in Figures 1(a) and 1(b), the performance of interactive video is enhanced using RMPSR as compared to SMR and DSR, in the sense that both the ratio of bad frames to total number of frames, and the number of bad periods are reduced. MDC can potentially be a suitable match for multipath communication in a sense that even only one path is broken, packets corresponding to the other description on the other path can still arrive at the receiver on time. With MDC, quality of these frames is still acceptable. To fully utilize this property of MDC, it is important for multipath routing protocols to maintain multiple routes as long as possible. RMPSR builds more than two nearly disjoint routes in the route request process and triggers new route request process before all the routes are broken. These steps help RMPSR maintain multiple routes longer than SMR and DSR. Another reason for the enhanced performance of RMPSR is its effective packets salvaging scheme. Our simulations with ten 12 kbps cross traffic flows also confirm that RMPSR outperforms both SMR and DSR.

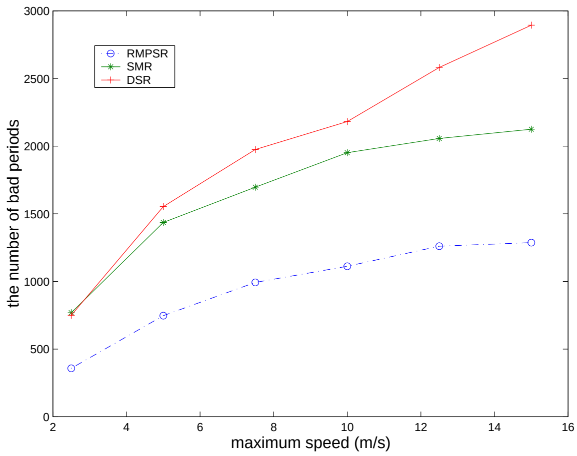
3.3. Performance evaluation of video on-demand applications

We compare RMPSR, DSR, and SMR for video on-demand applications with FEC. Simulations are run for 600 seconds. The bit rate of video stream is 144 kbps. We use (100,75) Reed-Solomon erasure code, which takes 75 data packets and produces 25 redundancy packets in one block. Thus the total sending rate of video stream is 192 kbps. We use a simple per-packet allocation scheme to distribute both data and redundancy packets over two routes. The receiver first pre-buffers 5 seconds' worth of video packets before playing back. If a packet arrives after its playback time, it is discarded. When the playback buffer in the receiver is empty, the receiver stops playing temporarily, and re-buffers 5 seconds' worth of video packets before re-starting the playback. There are five random 12 kbps cross traffic sessions in the network. Other simulation settings are the same as that of simulations in the previous section.

Figures 2(a) and 2(b) show goodput ratio and the number of rebuffering averaged over 50 simulations as a function of maximum speed for the three routing protocols. In each figure, the lower plot shows the number of simulations in which a particular scheme performs as good or better than the competing schemes. Goodput ratio is ratio of the number of data packets played at the receiver to those transmitted from the video source. Since each video packet has a strict deadline, and is discarded if it arrives after its deadline, we use this metric rather than the successful packet delivery ratio; Number of rebufferings denotes how many times a receiver freezes during one experiment.

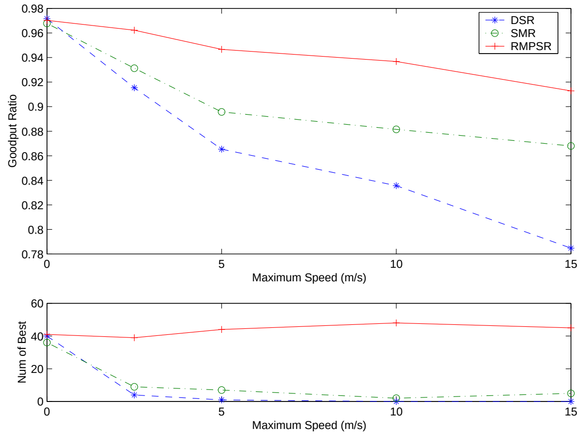


(a)

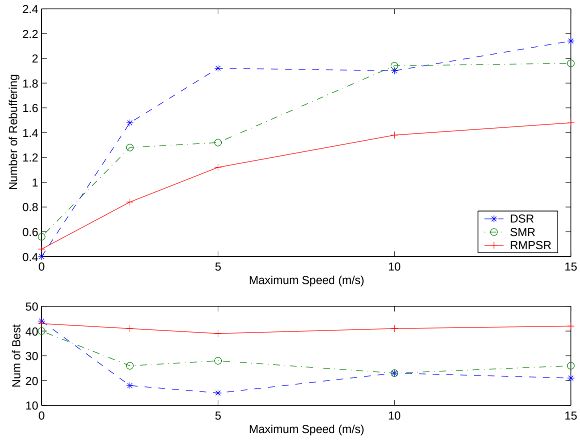


(b)

Figure 1. Performance evaluation for interactive video applications using MDC: (a) Ratio of Bad Frames; (b) Number of Bad Periods.



(a)



(b)

Figure 2. Performance evaluation for video on-demand applications using FEC: (a) Goodput Ratio; (b) Number of Rebufferings.

As seen in Figures 2(a) and 2(b), performance of all three protocols is similar in the static network, while their performance gap widens in more dynamic scenarios. As expected, as the maximum moving speed becomes larger, goodput ratio of all three protocols goes down, and ”number of rebufferings” goes up. However, RMPSR loses much fewer packets than either SMR or DSR protocol, and suffers fewer freezes at the receiver in dynamic scenarios. Since RMPSR builds multiple disjoint route sets, the connection is less likely to be broken than DSR or SMR. RMPSR also salvages packets at intermediate nodes with alternative routes, and triggers new route request process ahead of time. These steps further help RMPSR perform better in delay sensitive video applications.

4. Multiple tree multicast video communication over wireless ad hoc networks

Our proposed multiple tree multicast video communication system consists of two parts: a multicast routing protocol to construct multiple disjoint trees, and a scheme to distribute video packets into different trees. In this section, we propose a distributed serial multiple disjoint trees multicast routing protocol called Serial MDTMR, which builds two disjoint multicast trees in a distributed way, for multiple tree multicast streaming. The Serial MDTMR achieves reasonable tree connectivity while maintaining disjointness of two trees. For interactive video applications, we use Multiple Description Coding (MDC) to form multiple video streams, and transmit different video streams through different trees simultaneously.

4.1. Multiple tree multicast video communication with MDC

In this paper, we mainly focus on interactive video applications. Each packet of an interactive video application has a strict delay constraint. If a video packet arrives later than its deadline, it is useless to the decoder. As such, it is desirable to drop late packets at the sender or in the middle nodes rather than attempt to transmit them after the deadline has passed. So techniques based on retransmission or Forward Error Correction Code (FEC) are unsuitable for interactive video applications, as they both increase the delay.

MDC is a natural scheme for multiple tree multicast video communication, especially for strictly delay constrained applications, e.g. interactive video. MDC is a source coding scheme in which the signal is compressed into multiple independent bitstreams in such a way that the quality of the reconstructed signal at the receiver improves as the number of received bitstream increases [22][23]. In this paper, we will primarily deal with two description coding. In this case, the video quality is at its best if both descriptions are decoded at the receiver, and still reasonable when only one description is available. Packets forming different bitstreams are transmitted through different trees simultaneously, so that even if some packets in one tree do not arrive at the destination on time, the receiver continues to decode and display packets corresponding to the other description on the other tree, resulting in acceptable video quality without interruption.

To fully utilize the property of MDC, it is important for multicast routing protocols to construct multiple node disjoint trees, so that tree failures are independent of each other. Thus there are two independent paths from the sender to each receiver, and the probability that two trees fail at the same time is much smaller than that of one tree.

4.2. Serial MDTMR protocol

Our proposed Serial MDTMR protocol constructs two disjoint multicast trees in a distributed way for multiple tree multicast communication. The basic protocol is described as follows. We first construct a shortest path multicast tree. Then after requiring all the middle nodes in the first tree not to be middle nodes of the second tree, we construct another shortest path tree. Since these two trees do not share middle nodes at all, they are node disjoint.

Serial MDTMR is a way of constructing two disjoint multicast trees. It can be easily applied on top of any suitable single tree multicast routing protocol. Without loss of generality, we design Serial MDTMR based on the On-Demand Multicast Routing Protocol (ODMRP) [11], since ODMRP has been demonstrated to perform well and is well known [12]. By comparing Serial MDTMR and ODMRP, we characterize performance gain obtained by the multiple tree multicast routing. We can also design Serial MDTMR based on other multicast routing protocol, exploiting their unique features.

4.2.1 Double Disjoint Tree Construction

Similar to ODMRP, group membership and multicast trees in Serial MDTMR are established and updated by the source on demand. When a multicast source has packets to send, it periodically triggers a two step multicast tree construction/refresh process. In the first step, the source broadcasts to the entire network a JOIN REQUEST message, which includes the tree ID. When a node receives a non-duplicate JOIN REQUEST message for the first tree, it stores the upstream node ID, and rebroadcasts the packet. When the JOIN REQUEST message reaches a multicast receiver, the receiver creates or updates the source entry in its Member Table. The receiver then unicasts a JOIN ACK message to the multicast source via the reverse shortest path. When a middle node in the reverse path receives a non-duplicate JOIN ACK message, it updates its corresponding forwarding state in the Forwarding Table, and forwards the message to its upstream node. Each middle node of the tree only forwards the JOIN ACK message once in one tree construction cycle.

After receiving the first JOIN ACK message, the multicast source waits for a short time period before broadcasting another round of JOIN REQUEST message to assure the disjointness of two trees. When a node receives a non-duplicate JOIN REQUEST message, it forwards the packet only if it is not a middle node of the first tree in this round. When the JOIN REQUEST message reaches a receiver, the receiver unicasts back a JOIN ACK message to the multicast source to set up the second tree.

We visualize the entire tree construction process in Figures 3(a) and 3(b). The dash lines show the underlying topology of the network, and solid arrows show the two trees. Extra control packets, which are not used to build the mulitcast tree, are not shown in the Figures. In the first step, Serial MDTMR builds the first tree with nodes 2, 4, and 5 as the middle nodes. In the second step, nodes 2, 4, and 5 simply discard any JOIN REQUEST messages they receive, thus not participating in the construction of the second tree; the middle nodes of the second tree are nodes 1 and 3. Note that Serial MDTMR can guarantee that there is no shared middle nodes between two trees, but can not guarantee that each receiver connects to both trees.

4.2.2 Multiple Tree Multicast Packets Forwarding

The application layer protocol sets a tree-flag in each packet's header to denote to which tree the packet should be

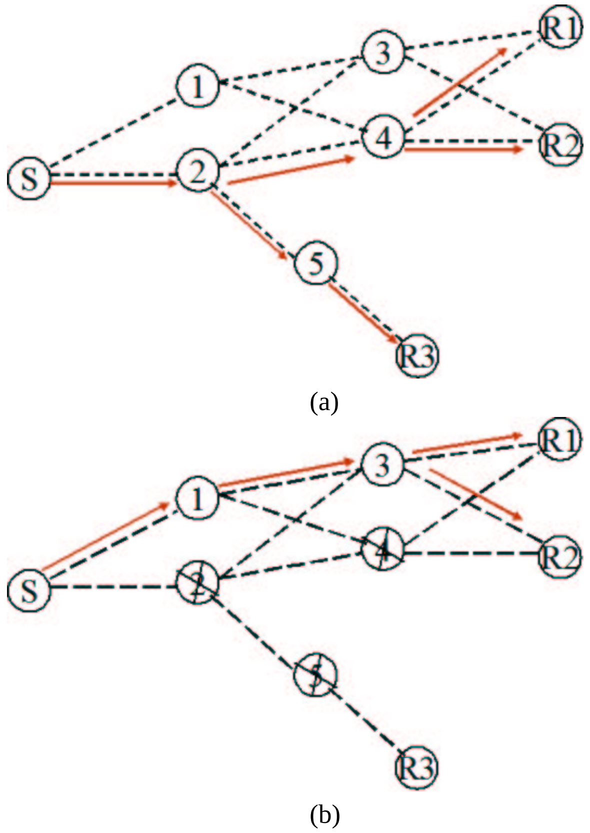


Figure 3. Double Disjoint Tree Construction: (a) the first tree; (b) the second tree.

forwarded. The Serial MDTMR forwards the packet in different trees according to the tree-flag. When a middle node receives a packet, it checks its Member Table, Forwarding Table and Message Cache to determine if it should forward the packet. The middle node forwards a non-duplicate packet only if the tree in which the packet is forwarded and the tree to which the middle node belongs are the same. Each packet flows along the corresponding tree from the sender to the receivers, but is not constrained to follow preset branches in the tree, as in the *tree flood* approach [13] or the *forwarding group flooding* approach [11]. Thus Serial MDTMR utilizes the broadcast nature of wireless ad hoc networks to obtain extra diversity gain without extra network resources. For example, in Figure 3(a), if the link between nodes 2 and 5 is broken, and node 5 receives data packets from node 4, node 5 continues to forward the packets to Receiver 3 since nodes 4 and 5 are both in the same tree. Thus packets loss is avoided even if some links in the tree are broken. Serial MDTMR does not support packet forwarding across the trees, since nodes in one tree are unaware of the nodes in the other tree.

4.3. Connectivity for multiple disjoint multicast trees

To achieve robustness in multiple tree video streaming, it is important for the trees to be as disjoint as possilbe. However multiple disjoint trees reduce connectivity level as compared to single tree [24]. Specifically, if double disjoint tree requires a significant increase in node density in order to keep a high connectivity level, it may be too expensive to implement in practical situations.

We begin by defining tree connectivity P as follows:

$$P \triangleq \frac{E[N]}{M} \tag{1}$$

where M is the product of the total number of receivers and the number of disjoint trees. $N = \sum_{i=1}^{m} n_i$, with n_i denoting the number of disjoint trees that receiver i connects to. Figure (4) shows the connectivity level of a topology for a case with three receivers and two disjoint trees. In this case, $N = \sum_{i=1}^{m} n_i = 5$, $M = 3 \times 2 = 6$, and tree connectivity is $P = \frac{E[N]}{M} = \frac{5}{6}$. Given a random topology with n nodes, one random sender and m random receivers, N is the sum of all receivers connecting to each multicast tree, and $E[N]$ is the expected value of N over all topologies. Intuitively, if the node density is low and radio range is small, it is difficult to construct trees that connect to all m nodes, and hence tree connectivity is expected to be low. On the other hand, for sufficiently high node density and sufficiently large radio range, we would expect the connectivity to be close to one, so as to construct trees that connect to almost all the receivers.

In previous work, we have shown that the required density for an ideal double disjoint tree scheme is not significantly larger than that of single tree scheme, and that tree diversity is a feasible technique to improve the robustness of multicast video transmission over wireless ad hoc networks [24]. We have also shown via simulations that the Serial MDTMR achieves reasonable connectivity while maintaining the disjointness [24].

4.4. Simulation results for multiple tree multicast communication with Serial MDTMR

We compare the performance of our proposed multiple tree multicast communication using Serial MDTMR with that of multicast communication using ODMRP [11] through detailed packet-level simulations in various mobility and communication scenarios.

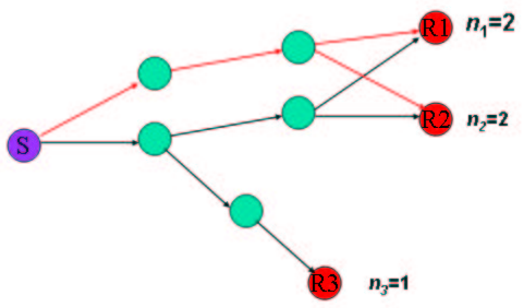


Figure 4. An example of computing tree connectivity level.

4.4.1 Simulation Scenario

We use a simulation model based on NS-2 [20]. The Monarch research group in CMU has extended the NS-2 network simulator to include physical layer, link layer and MAC layer models to support multi-hop wireless network simulations [21]. The distributed coordination function (DCF) of IEEE 802.11 for wireless LANs is used as the MAC layer. The radio model is based on the Lucent/Agere WaveLAN/OriNOCO IEEE 802.11 product, which is a shared-media radio with a transmission rate of 2 Mbps, and a radio range of 250 meters. A detailed description of the simulation environment and the models is available in [21].

The random waypoint model [21] is used to model mobility. Each node starts its journey from a random location to a random destination with a randomly chosen speed, which is uniformly distributed between 0 and maximum speed. Once the destination is reached, another random destination is targeted after a pause. We only consider the continuous mobility case with pause time of zero. To change the mobility level of the network, we vary the maximum speed from 2.5 m/s to 15 m/s. For each maximum speed, we randomly generate 30 different scenarios, and average the simulation results over those 30 scenarios.

In each run, we simulate a 65 node wireless ad hoc network within a 1350 x 1200 square meter area. Each simulation is 900 seconds long, and results are averaged over 30 runs. The movement of the nodes and application-layer communication traffic are generated in advance so that they can be replayed identically for different multicast communication protocols.

We randomly choose one sender and eight receivers. For the same quality of video, bit rate of MDC coding has been shown to be approximately 30% - 40% larger than that of SDC coding [23]. For fairness, we compare the performance of MDC with a bit rate of 62.4 kbps to that of SDC with a bit rate of 48 kbps. The frame rate is 8 frames per second (fps). For MDC, each frame consists of two 3.9 kilobits packets, each representing one description. If both packets corresponding to a frame are received before their deadlines, the frame is called a good one. If only one packet is received on time, the frame is called an acceptable one. Otherwise, it is called a bad frame. For SDC, each frame consists of one 6 kilobits packets. If the packet corresponding to a frame is received before its deadline, the frame is called a good one. Otherwise, it is called a bad frame. We consider interactive video applications in the simulation. The playback deadline of each packet is 150 milliseconds (ms) after it is generated.

4.4.2 Performance Metrics

We evaluate the performance of the multiple tree multicast communication with Serial MDTMR using the following metrics:

a. **The ratio of bad frames:** The ratio of the number of bad frames experienced in all the receivers to the total number of frames that should have been received in all the receivers. For example, in a multicast group with 1 sender and 5 receivers, each video frame should be received a total of 5 times across 5 receivers. If 100 video frames are transmitted, and the receivers experience 50 bad frames, the ratio of bad frames is 0.1. We use this metric rather than packet delivery ratio because it is more indicative of the quality of received video due to the following two reasons. First not all the received packets are useful for the video decoder, only those arrive on time. Second this metric reflects the fact that MDC can to some extent conceal the undesirable effects caused by missing packets.

b. **The number of bad periods:** A bad period consists of contiguous bad frames. This metric reflects the number of times received video is interrupted by the bad frames.

c. **Normalized packet overhead:** The total number of control packets transmitted by any node in the network, divided by the total number of video frames received by all the receivers. This metric represents the control packet overhead of the routing protocol normalized by the successful video frames received.

d. **Forwarding efficiency:** The total number of data packets transmitted by any node in the network, divided by the total number of packets received by all the receivers. This metric represents the efficiency of multicast forwarding of the routing protocol. For video applications, forwarding efficiency is more important than the control packets overhead, since the size of a video packet is generally much larger than the size of a control packet.

e. **Average hops of each packet:** The average hops that each packet takes. This metric represents the quality of the multicast trees as constructed by the multicast routing protocol.

4.4.3 Simulation Results

We compare the following three schemes:

Multiple tree multicast communication with Serial MDTMR and MDC;

Single tree multicast communication with ODMRP and MDC;

Single tree multicast communication with ODMRP and SDC.

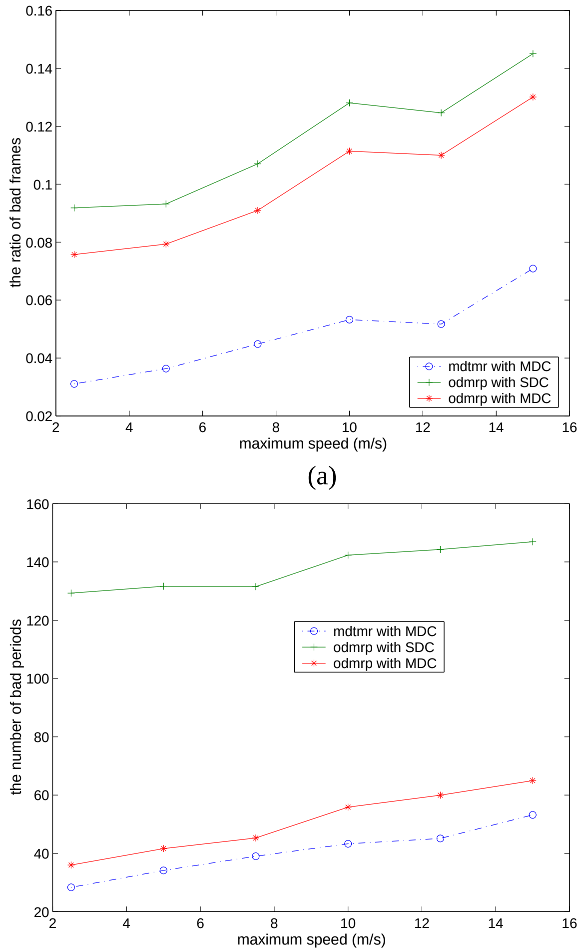
For fair comparison, both Serial MDTMR and ODMRP use 3 seconds for the JOIN REQUEST flooding interval, and use 4.5 seconds as a forwarding state lifetime.

Figures 5(a) and 5(b) show the result of the ratio of bad frames and the number of bad periods of the three schemes respectively. As expected, both the number of bad frames and the number of bad periods increase with maximum speed. As seen, Serial MDTMR with MDC outperforms the other two schemes for both metrics. MDC does not significantly reduce the ratio of bad frames for ODMRP, since it only constructs one tree. However MDC does significantly reduce the number of bad periods for ODMRP, indicating its effectiveness in reducing scattered packet loss caused by wireless channel error, or packets collision; nevertheless MDC does little to reduce contiguous packet loss caused by broken links of multicast tree.

Figure 6(a) shows the normalized control packets. The number of normalized control packets of Serial MDTMR is 50 percent higher than that of ODMRP, since in order to construct double disjoint trees, Serial MDTMR has to broadcast Route Request message twice in each routing cycle. The control packet count is not doubled because of the inefficiency in ODMRP resulting from each node periodically exchanging its membership table with its neighbors. In contrast, in Serial MDTMR, the receivers unicast back JOIN ACK message.

Figure 6(b) shows that the normalized forwarded data packets are almost the same for all three schemes with MDTMR being slightly better. This indicates that the performance gain of MDTMR with MDC is not obtained by forwarding a packet more times than the other two schemes, rather by the combined effect of independent trees and MDC. The normalized forwarded data packets is more important than the normalized control packets for video applications, since video application packets are generally much larger than control ones.

The average number of hops travelled by each packet is shown in Figure 6(c). Although the second tree obtained by Serial MDTMR is always worse than the first one, the difference between the schemes is insignificant. Specifically the average number of hops travelled by each packet in Serial MDTMR is only approximately 0.1 higher than that using ODMRP.



(a)

(b)

Figure 5. Performance evaluation for interactive video: (a) The ratio of bad frames; (b)The number of bad periods.

5. Conclusions and Future Work

In this paper, we have studied the problem of real-time video communication over wireless ad hoc networks. We have introduced new schemes based on path diversity and multiple description coding to provide robustness for both unicast and multicast video applications. For the unicast case, we proposed robust multipath source routing protocol to provide multiple paths, and showed via simulations that our proposed scheme outperforms existing ones for both interactive video applications and video on-demand applications. For the multicast video streaming, we proposed multiple tree video multicast communication with MDC to provide robustness for video multicast applications. We proposed a distributed double disjoint trees multicast routing protocol called Serial MDTMR to faciliate multiple tree video multicast. This scheme achieves reasonable tree connectivity while maintaining disjointness of two trees. Simulations show multiple tree multicast communication using the Serial MDTMR outperforms single tree multicast communication.

A possible direction of future work is to study ways to reduce the routing overhead while maintaining the ability to find disjoint routes.

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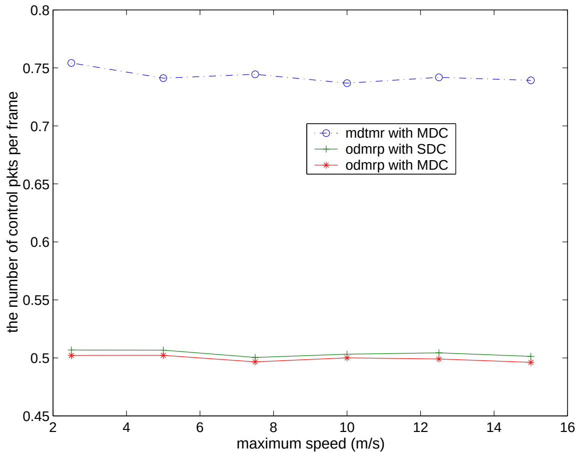
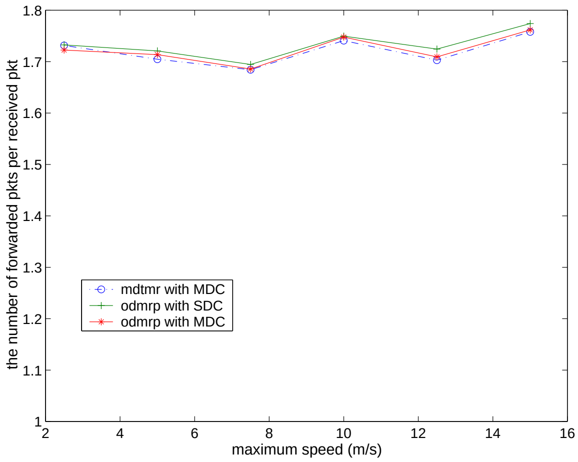


(a)



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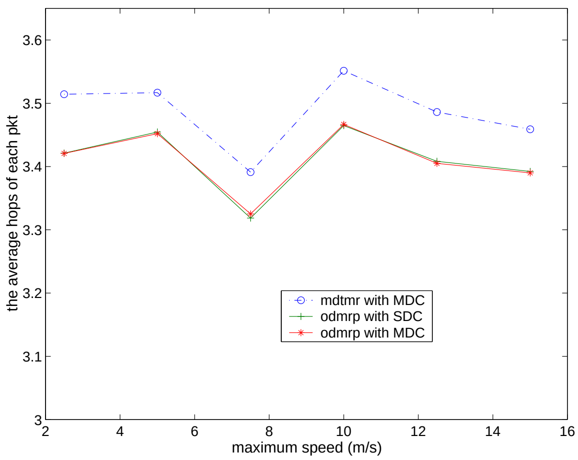

(c)

Figure 6. Performance evaluation for Serial MDTMR: (a) The normalized control packets; (b) The normalized forwarded data packets; (c) The averaged number of hops.