Multilayered Multicast Algorithms for Ad Hoc Wireless Networks

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Abstract: - In this paper, we address the issue of multilayered multicast routing in wireless ad hoc networks (WAHNs). Existing multilayered multicast protocols assume homogeneous ad hoc wireless networks. A more realistic assumption is a heterogeneous network; in which nodes have different processing, communication capabilities and other characteristics. In this paper, we assume heterogeneous network; in which nodes have different capabilities. Two multilayered multicast routing schemes are proposed, namely, Multiple Trees Based on Shortest Path Tree (MSPT) and Multiple Trees based on Steiner Minimum Tree (MSMT). We assume that each destination has a preference number of video layers; which is equal to its capacity. The basic idea is to: (i) construct tree(s) that can meet the destinations' QoS requirements, i.e., the number of required video layers (ii) distribute a number of video layers across the nodes. (i) and (ii) are done in a centralized manner, i.e., by the multicast source node. Simulations show that the proposed schemes greatly improve the QoS requirements (improve user satisfaction ratio) for a set of destinations. In addition, simulations show that multiple trees schemes achieve substantially higher satisfaction ratio than the single tree schemes.

Keywords: Heterogeneous ad hoc networks, Hierarchical encoding, Multilayer multicast, Multiple Trees.

1. Introduction

Ad Hoc Wireless Networks (AHWNs) are comprised of fixed or mobile nodes connected by wireless channel without the support of any fixed infrastructure or central administration. The nodes are self-organized and can be deployed "on the fly" anywhere any time to support a certain purpose.

Multicasting plays a crucial role in ad hoc wireless network to support several applications (multimedia application and group meeting, etc). In traditional multicast routing, all destinations nodes receive the same amount of multicast data. In contrast to traditional multicast, not all destinations nodes in multilayered multicast receive the same amount of data. Each destination node has a preference values for each layer of streams (QoS level) not only according to its available bandwidth but also according to its capacity (how many layers it can process).

A hierarchal encoding technique was proposed for efficient use of resources in heterogeneous networks [1]. This technique is a layered way of encoding information that can appear in different quality levels such as audio and video data. There are two types of hierarchical encoding techniques, namely, Layered coding (LC) and Multiple Description Code (MDC). In (LC) video or audio is encoded into a set of layers, one basic layer and some enhancement layers. The basic layer is enough for decoding the video or audio sequence but in the lowest quality, and the reception of enhancement layers is necessary to decoding higher quality. The l^{th} layer has the data which can further improve the quality of the video decoded from the 1st layer (the basic layer) and the 2^{nd}, ... and $(l-1)^{th}$ layers (the lower extended layers) [2]. (MDC) has been proposed as an alternative to (LC) for streaming over unreliable channels [3-6].

In contrast to (LC), Multiple (MDC) is a coding technique which fragments a single media stream into n independent sub streams $n \geq 2$ referred to as descriptions. The packets of each description are routed over multiple, (partially) disjoint paths. In order to decode the media stream, any description can be used; however, the quality improves with the number of descriptions received in parallel. The idea of (MDC) is to provide error resilience to media streams. Since an arbitrary subset of descriptions can be used to decode the original stream, network congestion or packet loss, which is common in best-effort networks such as the Internet, will not interrupt the stream but only cause a (temporary) loss of quality. The quality of a stream can be expected to be roughly proportional to data rate sustained by the receiver [7, 8].

The rest of the paper is organized as follows. Related work is presented in the next section. In section 3, we presented the formulation of the problem and the assumptions. Also, we presented the proposed algorithms and we analyzed their complexity. Simulation results and analysis are discussed in section 4. Finally, section 5 concludes the paper.

2. Related Work

Several multicast routing protocols have been proposed for ad hoc wireless networks. Multiple tree protocol called Robust Demand-driven Video Multicast Routing (RDVMR) protocol have been proposed in [9]. RDVMR exploits the path diversity and error resilience properties of Multiple Description Coding (MDC). It constructs multiple trees in parallel with a reduced number of shared nodes among them to provide robustness against path breaks. A novel path based Steiner tree heuristic have been proposed to reduce the number of forwarding nodes and as a result reducing the total data overhead.

In [10], two multiple tree multicast protocols have been proposed. The first scheme constructs two disjoint multicast trees in a serial (serial multiple disjoint trees multicast routing protocol (serial MDTMR)), but distributed fashion. In order to overcome routing overhead and construction delay, parallel multiple nearly-disjoint trees multicast routing protocol (parallel MNTMR) is proposed. Both protocols exploit MDC to provide robustness for video multicast applications. Multiple paths/trees in parallel are constructed to meet the QoS requirements is proposed in [11]. Three multicast routing schemes are proposed, namely; shortest path tree based multiple paths (SPTM), least cost tree based multiple paths (LCTM) and multiple least cost trees (MLCT). Each of the three schemes has a different objective, such as minimizing the delay of the call or minimizing the overall network cost. Link bandwidth nor node capacity (destinations' heterogeneity) are not considered in [9, 10]. Both protocols construct multiple trees and exploit MDC in order to provide error resilience. If one path is broken, packets corresponding to the other description on the other path can still arrive to the destination. In [11] link bandwidth (number of free timeslots) is taken into consideration. This protocol does not support heterogeneous destinations, *i.e.,* it assumes that all destinations must have the minimum required bandwidth, two timeslots, and they will receive the same multicast data.

3. Problem description and Assumptions

3.1 Network Model

We model the topology of the ad hoc network as a connected graph $G(N,L)$, where N represents a set of wireless nodes each with a random location, denoted by $N=\{1,2,...,n\}$ and L represents the set of wireless communication links between nodes. A link between node pair $\{u,v\}$ indicates that both nodes u and v are within each other's transmission range. We assume that all nodes have the same transmission range. In other word, if there is a link $l=\{u,v\}$, $l\in L$, it indicates v is within u's transmission range and u is within v's transmission range. Thus, the corresponding graph will be an undirected graph.

3.2 Assumptions

In this paper, we consider a session with single multicast source node. The layered video encoder (multicast source) can generate M layers, for simplicity we assume $M=3$. Nodes in the network have different capacities. We define the capacity by how many video layers can be handled (received and retransmitted) by a node assuming that all nodes have the capability of receiving all the transmitted layers There are several factors that can limit the capacity of a node, namely but not limited to, remaining power, number of sessions participating in, buffer size and the type of the node (laptop, PDA, …).

We always assume that the multicast source has a capacity of three. The transmission of a specific number of layers between two nodes does not depend only on the available link bandwidth between the communicating nodes, but also on the capacity of each node. We assume that an arbitrary link $l\{u,v\}$, $l\in L$, between node pair $\{u,v\}$ have always $BW(M)$, where $M=3$ represents the number of video layers and $BW(M)$ is the total bandwidth required for the three video layers. The capacity of link $l, l\in L$, can be defined as follows:

$$C(l)=\min\{C_n(u),C_n(v)\} \qquad (1)$$

Where $C_n(u)$ and $C_n(v)$ represent the capacity of nodes u and v, respectively.

3.3 Topology Construction

Our topology is constructed as follows:

(i) We first setup a random graph by creating N nodes whose coordinates are distributed uniformly in a square area 1000*m* X 1000*m* and setting the transmission range of nodes to be $R = 250m$.

(ii) Uniform random capacities are distributed over the nodes in the network, where the probability of generating a capacity of 1, 2 or 3 is equal to $1/3$.

(iii) A wireless communication link is existing between two nodes u and v if the distance between them $d\{u, v\} \le R$.

(iv) A multicast source s is randomly selected and if $C_n(s) < 3$, we set $C_n(s) = 3$.

(v) A number of destinations (multicast group) are randomly picked up from the network graph such that any destination is at least 2-hops away from the multicast source s .

(vi) A directed graph (partial topology) is constructed by a multicast source. It contains the multicast group and the forwarding nodes. The directed graph is identified by a virtual (logical) number of levels with a multicast source node as the first level, its neighboring node are in the second level and so on. The multicast source should know the capacities and available links bandwidth of the partial topology.

3.4 Multiple Trees Multicast Routing Algorithms

In this section, we present two algorithms for constructing multiple trees for multicast video layers transmission and describe the distribution of video layers among different multiple trees. Our goal is to construct multiple trees to maximize the USR defined in (2). The two algorithms are, Multiple Trees Based on Shortest Path Tree (MSPT) and Multiple Trees based on Steiner Minimum Tree (MSMT).

3.4.1 Multiple Trees Based on Shortest Path Tree (MSPT)

Shortest path tree constructs a multicast tree with shortest path from a multicast source node to every destination node. Single shortest path tree that meet the QoS requirement (the number of video layers) may not be existed, even though there are enough resources in the network. Thus, MSPT can greatly increases the number of video layers delivered to each destination. Based on the partial topology, a multicast source constructs multiple/single SPT and assigns the video layers to all nodes on the trees. Fig. 1 provides flow diagram for multiple trees construction and video layers assignment.

3.4.2 Multiple Trees based on Steiner Minimum Tree (MSMT)

Steiner minimum tree algorithm constructs a tree (multicast tree) that spans all the multicast group members with minimum number of links. The construction of the MSMT is based on the Steiner tree algorithm described in [12]. Again, the construction of the second tree and third tree depends on the capacity of the multicast group members as discussed in the previous section.

3.4.3 Algorithms Complexity

We analyze the complexity of the proposed algorithms as follows. For MSPT, the shortest path algorithm (Dijkstra's algorithm) is of complexity $O(|V|\log|V| + |E|) \le O(|V|^2)$ where $|V|$ and $|E|$ is the number of nodes and number of wireless communication links in the partial topology, respectively. Since it iterates $|M|$ times, where $|M|$ is the number of destinations; therefore the complexity is $O(|V|^2 \times |M|)$ and finally the algorithm iterates $|C|$ times, where $|C|$ is the value of maximum capacity of the destination set. As a result, the complexity of MSPT is given by $O(|V|^2 \times |M| \times |C|)$.

For MSMT, the complexity of the Steiner tree algorithm is $O(|S||V|^2)$ where $|S|$ is the set of multicast group members (source and destination nodes only). Since MSMT iterates $|C|$ times, as a result, the complexity of MSMT is given by $O(|S||V|^2 \times |C|)$.

4. Simulation Results and Discussion

In order to evaluate the performance of the proposed algorithms, extensive simulations have been conducted and compared. In the following simulation experiments, 2000 topology are constructed and the value of each point in the various figures is the mean value of the total number of simulation runs (2000 topologies). To fairly compare the proposed algorithms, for each generated random graph (topology), all the proposed algorithms (multiple/single trees) are applied and USR (equation (2)) and the number of forwarding nodes are calculated. In addition, at each simulation run, *i.e.,* each generated random topology, Breadth-First Search (BFS) is performed to examine if the generated topology is connected (at least there is one path between any two nodes) or not. If the topology is not connected, simply discard it; otherwise continue the simulation steps in section 3.3. Our metrics of interest are:

- *User satisfaction ratio (USR):* user satisfaction ration is measured by a fraction of the number of the requested video layers by destinations and the number of the received video layers. We define USR as follows:

$$USR = \left\{ \sum_{i=1}^{D} N_R(R_i) \Big/ \sum_{i=1}^{D} C_n(R_i) \right\} \times 100\% \qquad (2)$$

Where, D represents the number of destination, $N_R(R_i)$ is the total number of received video layers of destination R_i, and $C_n(R_i)$ is the capacity of destination R_i (*i.e.,* the total number of requested video layers).

- *Number of forwarding nodes:* number of forwarding nodes defined as the number of nodes on the multicast trees except the multicast source and the leaf destinations.

In the next sections, we perform two groups of simulations. In the first group, we vary the number of destination nodes (multicast group size) from 5 to 25 and we fix the network size (the number of nodes in the network) to 50 nodes. In the second group, we vary the network size from 50 to 100 and we also vary the multicast group size from 10 to 30. For both groups of simulation, the proposed algorithms for multiple/single trees were compared in terms of USR and number of forwarding nodes.

4.1 USR and Number of Forwarding Nodes versus Multiple Trees and Multicast Group Size

Fig. 2 plots the corresponding USR and number of forwarding nodes, respectively, of the two algorithms. Fig. 2(a) shows the changes of USR with different multicast group size. As the number of multicast group size increases, USR decreases regardless which algorithm is used. Fig. 2(b) shows that as the number of destinations increases; the number of forwarding nodes increases. Both algorithms have the same number of forwarding nodes.

4.2 USR and Number of Forwarding Nodes versus Multiple Trees and Network Size

Fig. 3(a) shows that for a fixed number of destinations (for both algorithms), as the network size increases USR increases. In addition, as the number of destinations increases from 10 to 30, USR decreases. Fig. 3(b) illustrates that the number of forwarding nodes (for both algorithms), increases as the network size increases. When the number of destinations increases from 10 to 30; the number of forwarding nodes increases (for both algorithms). MSMT algorithm has less number of forwarding nodes for both destinations set 10 and 30 when compared with MSPT algorithm.

4.3 USR and Number of Forwarding Nodes versus Single Tree and Multicast Group Size

In this experiment, we compare USR and number of forwarding nodes of the Single Shortest Path Tree (SSPT) algorithm and Single Steiner Minimum Tree (SSMT) algorithm versus the multicast group size. For both algorithms, as the number of destinations increases; USR decreases. On average, SSPT and SSMT have the same USR (about 65%), but SSMT have less number of forwarding nodes than SSPT. This is shown in Fig. 4.

4.4 USR and Number of Forwarding Nodes versus Single Tree and Network Size

Fig. 5(a) shows that for a fixed number of destinations, for both algorithms, as the network size increases USR increases. In addition, as the number of destinations increases from 10 to 30, USR decreases. Also Fig. 5(a) shows that both SSPT and SSMT achieve approximately the same USR for the same number of destinations. Fig. 5(b) illustrates that the number of forwarding nodes (for both algorithms), increases as the network size increases. When the number of destinations increases from 10 to 30; the number of forwarding nodes increases (for both algorithms). SSMT algorithm has less number of forwarding nodes for both destinations set 10 and 30 when compared with SSPT algorithm.

4.5 USR and Number of Forwarding Nodes versus Multiple Trees, Single Tree and Multicast Group Size

We compare in Fig. 6 the multiple trees algorithms and the single tree algorithms versus the multicast group size in terms of USR and number of forwarding nodes, respectively. Clearly, multiple trees algorithms achieve higher USR than the single tree algorithms. On the other hand, single trees algorithms achieve lower cost than the multiple trees algorithms.

4.6 USR and Number of Forwarding Nodes versus Multiple Trees, Single Tree and Network Size

In Fig. 7, we compare the USR and number of forwarding nodes of the multiple trees and single tree algorithms versus the network size. Fig. 7(a) shows that the multiple trees algorithms achieve higher USR than single tree algorithms. In addition, USR of multiple trees algorithms increases as the network size increases; on the other hand it (USR) insignificantly increases for the single tree algorithms. Fig. 7(b) shows that the single tree algorithms have smaller number of forwarding nodes than multiple trees algorithms.

5. Conclusion

We have presented the multilayered multicast routing in ad hoc wireless network. Two algorithms for constructing multiple trees to meet the requirements (number of video layers requested) of destination nodes were proposed and their complexities were analyzed. In addition, simple video layers assignment was proposed. Simulation results demonstrate that the multiple trees algorithms achieve higher USR as compared with the single trees algorithms with some increase in number of forwarding nodes.

In this paper, we assumed that the bandwidth for each link between any two nodes have an available bandwidth that is sufficient to handle at least three video layers. Future work will consider the variations of links bandwidth. Equation (1) can be modified as:

$$C(l) = \min\{C_n(u), C_n(v), BW(l)\} \qquad (3)$$

where $BW(l)$ is the available link bandwidth.

Multicast trees construction and video layers assignment are done in a centralized manner, *i.e.,* by the multicast source. However, it can be done in a distributed manner. Since MDC generates independent number of video layers (descriptions), therefore we can exploit this property to increase user satisfaction ratio defined in (2); this requires that the multicast trees should be constructed in a centralized manner. Future work will focus on that.

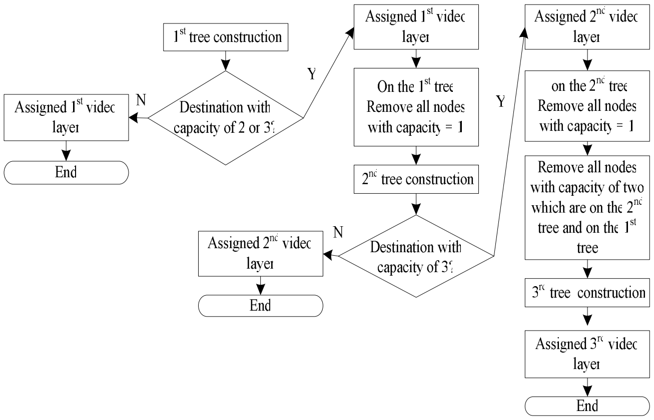
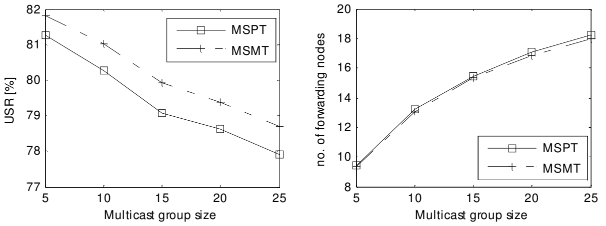
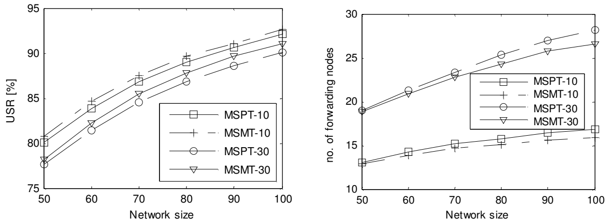


Fig. 1 Flow diagram for multiple trees construction and video layers assignment.



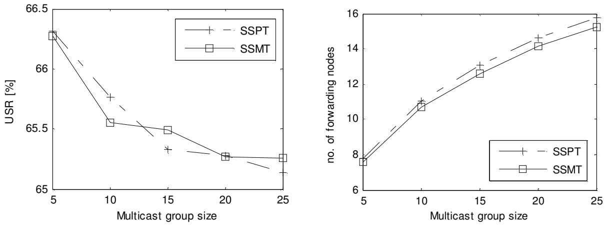
(a) (b)

Fig. 2: (a) USR and (b) Number of forwarding nodes for both MSPT and MSMT versus multicast group size and network size of 50 nodes.



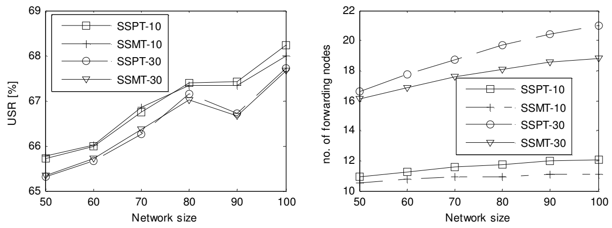
(a) (b)

Fig. 3: (a) USR and (b) Number of forwarding nodes for MSPT versus network size, with 10 and 30 destinations.



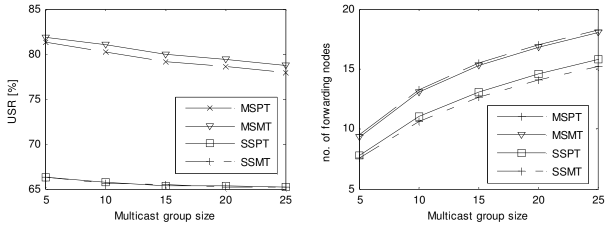
(a) (b)

Fig. 4: (a) USR and (b) Number of forwarding nodes for both SSPT and SSMT versus multicast group size and network size of 50 nodes.



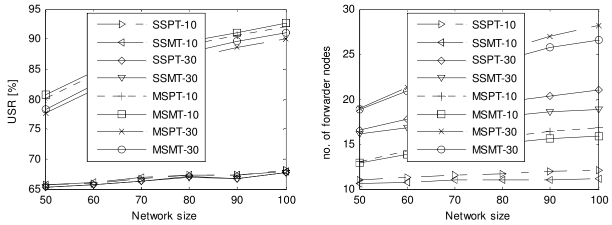
(a) (b)

Fig. 5: (a) USR and (b) Number of forwarding nodes for both SSPT and SSMT versus network size, with 10 and 30 destinations.



(a) (b)

Fig. 6: (a) USR and (b) Number of forwarding nodes for multiple trees (MSPT and MSMT) and single trees (SSPT and SSMT) versus multicast group size, with network size of 50 nodes.



(a) (b)

Fig. 7: (a) USR and (b) Number of forwarding nodes for multiple trees (MSPT and MSMT) and single trees (SSPT and SSMT) versus network size, with 10 and 30 destinations.

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