The Effect of Using P-XCAST Routing Protocol on Many-to-Many Applications

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Abstract: *There are two types of wireless networks, infrastructure wireless network and wireless Ad-hoc networks. Wireless Ad-hoc networks are well suited for use by emergency response teams, for search and rescue operations that require team-based communications in the absence of working telecommunications infrastructure, while infrastructure networks require the existence of access point in which all the communications are done through it. Unfortunately, wireless Ad-hoc networks suffer from limited bandwidth and QoS constraints. A Priority eXplicit multiCAST based routing protocol (P-XCAST) is presented in this paper to support team-based many-to-many communications in wireless Ad-hoc networks. eXplicit multiCAST (XCAST) is well suited for supporting a large number of small groups effectively, in comparison with multicast based protocols. However, since XCAST was initially designed for wired networks, it was not optimized for wireless Ad-hoc network use. The proposed P-XCAST protocol enhances XCAST for wireless Ad-hoc network use by modifying the route request mechanism in AODV to build the network topology, and route data packets containing the list of destinations for a given group in the XCAST header, by classifying the destinations according to similarities in their next hop neighbors and hop counts. A single data packet is XCAST in lieu of sending n unicast data packets to n destinations with the same next hop neighbor. In addition, P-XCAST is merged with a new mobile group management protocol to handle mobility of group members. In this paper, P-XCAST was tested using topologies with different sources that were sending and receiving data at the same time to handle foreground and background many-to-many applications. The results of simulation experiments show that P-XCAST achieved better QoS performance compared with other routing protocols for small group sizes typical of group communications applications such as Push-To-Talk (PTT).*

Keywords: *MANETs, P-XCAST, QoS, PTT.*

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1. Introduction

Group-based communications in Ad-hoc networks are frequently needed to support search and rescue operations in the absence of working telecommunications infrastructure. Communications services such as Push-To-Talk (PTT) were previously implemented using dedicated radio equipment. With the move towards IP-based converged network access, the implementation of PTT services and other group-based communications using IP becomes crucial. Since such group-based communications are characterized by multiple small-sized teams operating within a geographical area of interest, effective team or group-based routing protocols are necessary to support the effective use of limited wireless bandwidth.

In this paper, the Priority eXplicit multiCAST based routing protocol (P-XCAST) is proposed to minimize the bandwidth consumption for supporting small-sized group applications in wireless Ad-hoc network, such as PTT applications. A group management protocol is proposed and merged with P-XCAST to handle group management during mobility of members by having two types of nodes: members and group heads. A group membership management scheme was developed to discover the network topology and determine group heads and group members in the given network. P-XCAST routing based on the AODV Route Request mechanism was then used to send data packets to the group members through their group heads. The proposed approach was compared with other routing protocols such as: AODV, WRP, LAR1 and ODMRP using the GloMoSim network simulator. This paper is structured as follows: section 2 provides an overview of related work for wireless Ad-hoc networks, small-group based routing algorithm and XCAST routing functionality. A new P-XCAST routing algorithm design is described in section 3. Performance evaluation using QoS metrics for comparison between P-XCAST and other routing protocols under different group size using many-to-many applications are presented in section 4. Finally, section 5 summarizes the results and describes future work.

2. Related Work

2.1. Wireless Ad-Hoc Networks

Wireless and Mobile Ad-hoc Networks (MANETs) consist of multiple mobile devices spread out in a fixed area that establish peer-to-peer communications among themselves. MANETs can support multi-hop communications through IP routing, via two classes of MANET routing protocols: reactive or on-demand protocols and proactive protocols. Reactive protocols decrease overheads by only initiating a request when required, so they are more suitable for dynamic topologies; however this mechanism creates a setup delay when building new routes [6]. Ad-hoc On-Demand Distance Vector (AODV), Location Aided Routing (LAR), and Dynamic Source Routing (DSR) protocols are examples of reactive protocols [3, 4, 15]. The main difference between AODV and DSR is that AODV is a distance vector routing protocol that only stores the next hop information in its routing table.

Proactive protocols periodically broadcast a control information message across the network in order to build or update routing table for every node. Wireless Routing Protocol (WRP) is an example of proactive protocols that maintains routing information through the exchange of triggered and periodic updates [2].

2.2. Group Communications Protocols

Multicast is a technique that is developed to transmit packets from one location (the sender) to other locations (the receivers), the multicast source send or transmit packets using multicast group address, so only the members in the group can receive the data, and this differentiate multicast from broadcast in which the sender float the network. There have been many trends to adapt multicast towards wireless Ad-hoc networks usage, examples include On-Demand Multicast Routing Protocol (ODMRP) [14] and Multicast Ad-hoc On-demand Distance Vector (MAODV) [18].

Since Quality of Service (QoS) is a crucial features of multimedia group applications such as PTT, whereas wireless bandwidth is a scarce resource, efficient use of bandwidth is critical for supporting QoS for such applications. For example, QS-AODV [17] adds new QoS features to AODV, by modifying RREQ, RREP and RERR messages by adding the session ID and the required bandwidth for a given QoS flow. Two major goals for QS-AODV were: path selection that satisfies the QoS requirement, and detection and repair of broken links. There are two types of group communication: one-to many, and many-to-many group communication. In addition, many-to-many applications can be classified into two types: foreground group communications and group communications with background traffic. In foreground group communication all the group sources are assumed to be CBR applications with identical data traffic loads of 13.2kbps, while in group communications with background traffic, FTP transfers were occurring in the background at the same time as CBR sources were transmitting in the foreground. The 13.2kbps data traffic load was used to approximate the behavior of the GSM 6 Codec which is suitable for PTT real time applications [16].

2.3. XCAST Routing

XCAST is a multicast scheme designed to support networks with a large number of groups, where each group only has a small number of members (receivers). This is achieved by encoding the list of destinations in the XCAST header [12]. XCAST was initially proposed for use in wired networks, several proposals to adapt XCAST for MANETs were mentioned in [7], since XCAST minimizes the traffic load in the link from the source to the rest of network topology. So the use of XCAST as a group routing algorithm helps in reducing the traffic load in the links, since XCAST packets are only duplicated when the network route branches, to reach specific receivers.

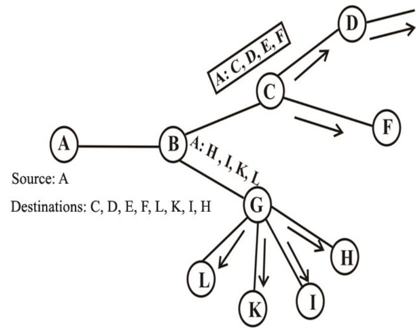

Figure 1. XCAST packets delivery mechanism.

For example, link BG in Figure 1 will encounter only one XCAST packet instead of four Unicast packets, where L, K, I, and H are receivers reached via that link. Consequently, the reduction of network traffic enhances QoS metrics.

3. P-XCAST for Group Based Application

3.1. Group Membership Management

Mobile Ad-hoc networks are characterized by dynamic topology, where nodes change places frequently, so a new group management algorithm is adapted over P-XCAST routing protocol to handle group management by assigning two types of nodes: Group Head (GH), and member nodes. Here, group head nodes play the role of servers in push to talk application, as the current industrial solution for push to talk application are centralized and suffer from the scalability problem, excessive end-to-end delay, and compatibility with other applications [11]. GH election is based on the lowest ID heuristic by assigning a distinct ID for each node similar to two hop Linked-Cluster Algorithm (LCA) [9].

As the lowest ID algorithm performs better than other cluster head election algorithms. Group formation starts from the instant the group head is elected. After the group head has been assigned, each group head forms a group through the use of the following control messages:

- *Join Packet:* This packet is sent periodically by moving nodes or members towards the nearest GHs to distribute nodes or members to their assigned servers. Figure 2 describes the structure of join packet with its assigned fields.

Type	Group Head Address	Member Address	Src. Address	Flow ID

Figure 2. Group management control packet structure.

- *Clear to Join Packet:* The packet is sent from the nearest group head to the member or node that request a join if the group head has no problem to accept the node request. The first received clear to join packet reflects that this GH is the node's head or server, since this packet indicates that it is the nearest server with the lowest number of hop count or least cost link with respect to congestion. It has the fields that are described in Figure 3.

Type	BCAST ID	Group Head Address	Member Address

Figure 3. Clear to join packet structure.

- *Update-Life Time Packet:* Member nodes need to keep their state with their group heads if they are still within the same domain, so within a specific period of time every member needs to update its state with its group head or server by sending an update-life time packets to their group heads as members and group heads nodes may change their position rapidly during their movement from one domain to another. It has the same fields as join packet fields described in Figure 2.
- *Updated Packet*: This packet is sent from group heads to their members annoying them that they have updated their routing tables and adding them to their live members. It has the same fields as clear to join packet fields described in Figure 3.
- *Error Packet:* This packet is defined to solve the error that may happened if a data packet is sent to a specific group head to forward it to its member, while this member changed his group head and entering a new group head coverage area. It has the following fields: Type, group head address, member address, *Src*. Address and flow ID as it is depicted in Figure 4.

Type	BCAST ID	Src. Address	Flow ID

Figure 4. Error packet structure.

The first step for applying the P-XCAST protocol in MANETs starts with determining the destinations that the sender wants to send data to, by defining a list of destinations for the source application. Hence applications must be P-XCAST enabled to manage the group membership list. Data packets are then sent to the transport layer (typically UDP) [1], which was also modified to enable the use of P-XCAST since the original network layer protocol was designed to handle a single destination address only.

3.2. P-XCAST Routing Algorithm

It was noted that source advertising is more efficient and controllable than destination advertising [10]. The proposed P-XCAST protocol for MANETs is based on source advertisement. We propose the combination of source advertisements and on demand routing requests to reduce overhead, based on the AODV routing protocol. P-XCAST operates in the following three phases:

1. *Route Request Phase:* The route request packet consists of the following fields: packet type, source address, destination address, sequence number, destination number, flow Id, and Time To Live (TTL) Figure 5. This control packet is sent periodically by the sender nodes to discover the route to the receiver nodes for the group-based application.

Type	Src. Address	Dest. Address	SNo	Dest. No.	Flow ID	TTL

Figure 5. P-XCAST route request control packet.

2. *Route Reply Phase:* The route reply packet is the response generated by each destination for every source that send a route request packet, and consists of the following fields: packet type, source address, destination address, destination number, and hop count Figure 6.

Type	Src. Address	Dest. Address	Dest. No.	Hop Count

Figure 6. P-XCAST route reply control packet.

3. *Data Forwarding Phase:* Data packets to be sent to a particular group are passed to the P-XCAST network routing layer, where the P-XCAST routing algorithm would perform the following actions to classify and build the correct XCAST header for subsequent transmission this is illustrated in Figure 7. The P-XCAST data packet contains the list of all destination that the sender wants to send data packet to, some of these destinations may already exist in the routing table of the node. Other destinations not found in the routing table would trigger a route request, until all nodes have been updated in the P-XCAST routing table as shown in Figure 8. After the routing table is updated, then the list of destinations is grouped into P-XCAST sub-lists according to the next hop information. A number of P-XCAST packets equal to the number of sub-lists

are created and the P-XCAST header information updated for each of the packets. Finally, the new packets are forwarded to the next GHs which forwards them toward their destinations. If the list of destinations for a subgroup is a single destination, it is sent as a unicast packet. For example, R1 and R2 belongs to GH1, R3 belongs to GH2, while R4, R5 and R6 belongs to GH3. So, GH1 will forward two packets to R1 and R2, and then GH2 will forward one packet to R3, while GH3 will forward three packets to R4, R5 and R6. The steps involved in route discovery to the respective receivers and the subsequent transmission of group data via the respective GHs is illustrated in Figure 9.

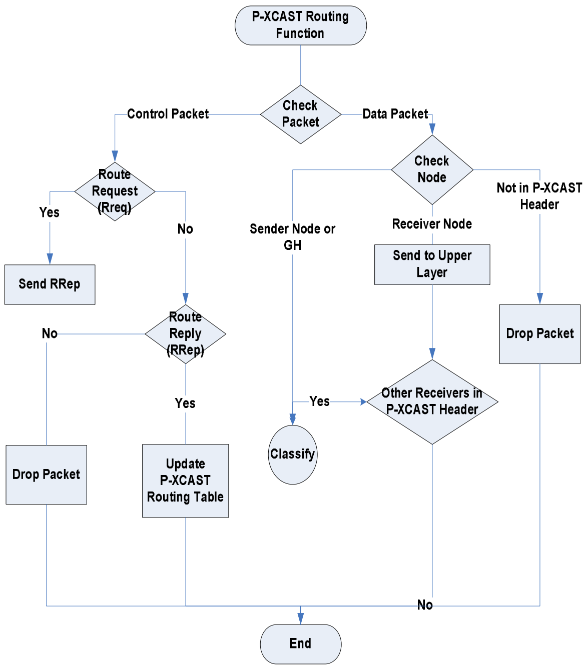

Figure 7. P-XCAST routing function.

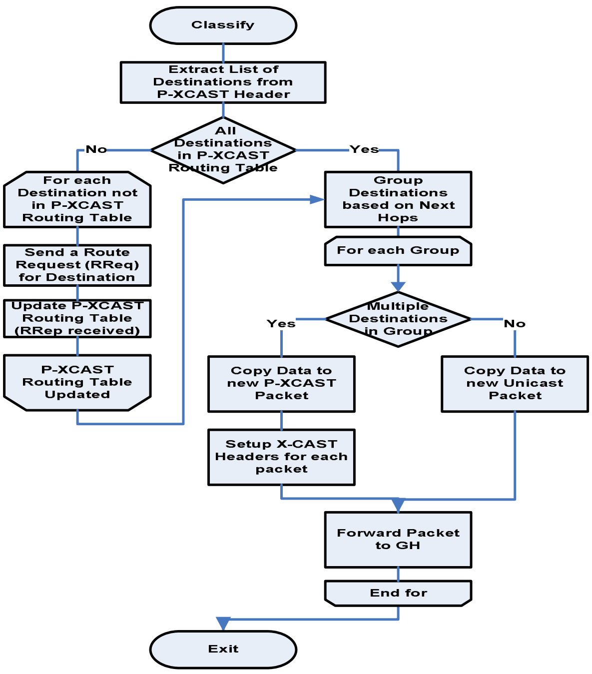

Figure 8. P-XCAST destination classifications.

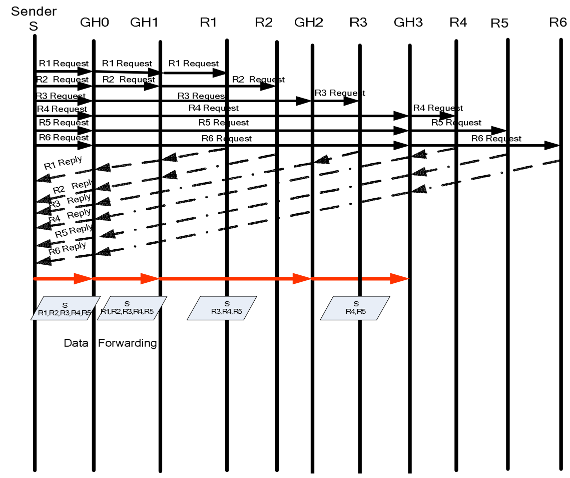

Figure 9. RREQ and RREP messages passing diagram.

4. Performance Evaluation

The GloMoSim network simulator [5] was modified to implement the P-XCAST algorithm and conduct various simulation experiments to compare its results with the other routing protocols. These simulation experiments were performed for an open area of 2000 m × 2000 m, for over 900 seconds of simulation time. The group application was represented by a P-XCAST enabled Constant Bit Rate (CBR) source which generates data to its group members at the rate 13.2kbps, corresponding to the GSM 6 Codec which is suitable for PTT real time applications. Nodes in the simulation were placed in a static topology which is shown in Figure 10. Different group sizes, starting from five members per group (small group size) to larger group sizes of thirty members per group were studied. The experiments were run ten times using different initial random seeds value and averaged to obtain the recorded value in the graphs. The efficiency of P-XCAST is evaluated through the following QoS performance metrics:

- *Throughput:* Defined as the data rate (bps), which is calculated as the total number of bit received divided by the difference between the reception time of the last packet and the reception time of the first packet.
- *Latency or End-to-End Delay:* Defined as the difference between the generation time of a packet in the source node and the reception time for this packet at each node.

$$\overline{D} = \frac{1}{n}\sum_{i=0}^{n} Di \qquad (1)$$

- *Jitter:* The variation of end-to-end transient or absolute data packet transfer delay [8].

$$V^2 = \frac{1}{n-1}\sum_{i=0}^{n}\left(Di - \overline{D}\right)^2 \qquad (2)$$

$$J = \sqrt{V^2}$$

- *Packet Delivery Ratio:* Defined as the ratio of number of packets received to the number of packet that should be received, and this factor is calculated to measure the efficiency of routing protocols in delivering packets to all groups.

$$\overline{PDR} = \frac{\sum No. of (P.received)}{Xlist \times No. of (P.sent)} \quad (3)$$

Where:

$\overline{PDR}$ = *Average Packet Delivery Ratio*
P.received = Packets received
P.sent = Packets sent

Xlist= the number of destinations in P-XCAST header

- *Group Reliability:* This metric is used to investigate the efficiency of routing protocol in transmitting data packets to all group destinations. Group Reliability (GR) was computed as the ratio of the number of packets that are received by 95% of the members in the group to the number of packets that were sent [13]. In other words, the packet is considered received if it is received by 95% of the receivers. Group reliability can be calculated as:

$$GR = \frac{\sum_{i=1}^{Ps} Pi}{Ps} \quad (4)$$

Where *Pi* represents the probability of packet *i* received by at least 95% of the receivers in the group and *Ps* is the number of data packet that were sent.

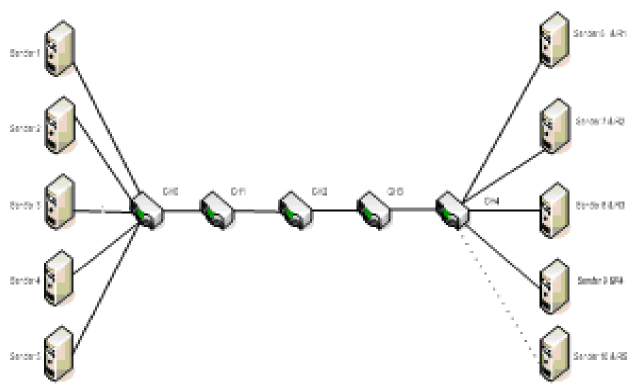

Figure 10. Network topology for many-to-many applications.

4.1. The Effect of Using Foreground Many-to-Many Applications on QoS Metrics

In this scenario the QoS metrics were studied by investigating the effect of using foreground many-to-many applications in which five senders were placed on the left of Figure 10, these senders were transmitting and receiving data at the same time. It is noted from the graph shown in Figure 11, that there was minor impact from increasing the number of receivers on the link throughput for P-XCAST, LAR1, AODV and ODMRP, while WRP experienced a decrease in link throughput above 15 receivers.

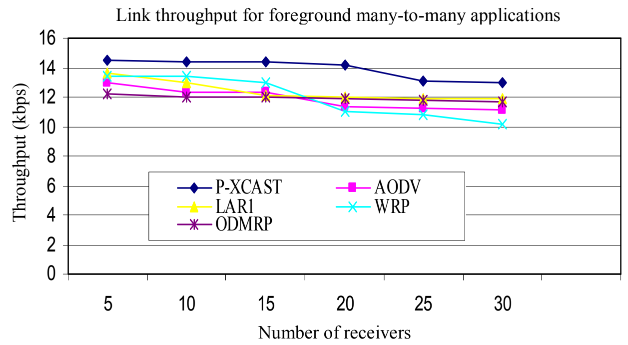

Figure 11. Link throughput for foreground many-to-many applications.

The major constraint on real time applications is the average delay, which should be minimized. The average delay for P-XCAST is less than that for AODV and LAR1. It is similar to WRP for ten receivers or less, since WRP is a proactive routing protocol that does not incur any delay for topology discovery. It is also similar in performance to ODMRP for until the group size exceeds 15 receivers Figure 12. Other protocols had much worse delay performance. So, the use of P-XCAST is recommended for PTT applications since it satisfies QoS requirements for a larger range of group sizes, especially when a group has fifteen or fewer receivers.

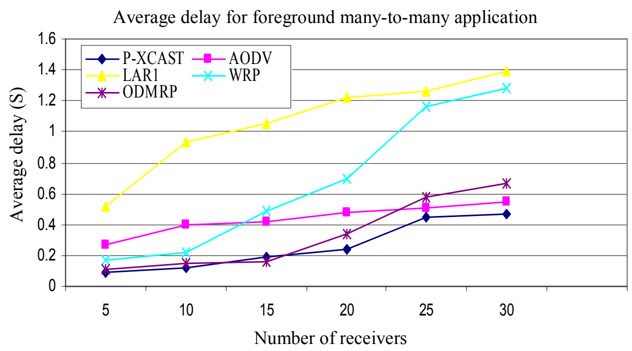

Figure 12. Average delay for foreground many-to-many application.

Jitter should also be minimized, since it affects the behavior of real time applications. The measured values for P-XCAST were less than the values obtained using AODV, LAR1, WRP and ODMRP. Figure 13 indicates that P-XCAST is superior to all other tested protocols for almost all group sizes, and it satisfies the QoS at group sizes of twenty five receivers or less, so P-XCAST is highly suited for PTT applications.

As shown in Figure 14, P-XCAST achieved better PDR values than other tested routing protocols. PDR values for P-XCAST is fairly constant and does not change too much with increasing group sizes, while values for AODV, LAR1 and WRP fell sharply when the number of receivers exceeded fifteen receivers, while PDR values for ODMRP were generally low for all group sizes.

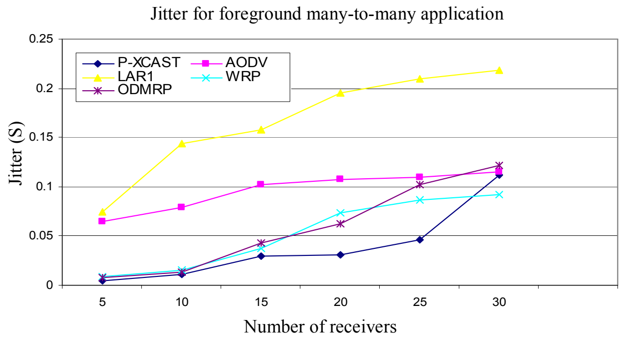

Figure 13. Jitter for foreground many-to-many application.

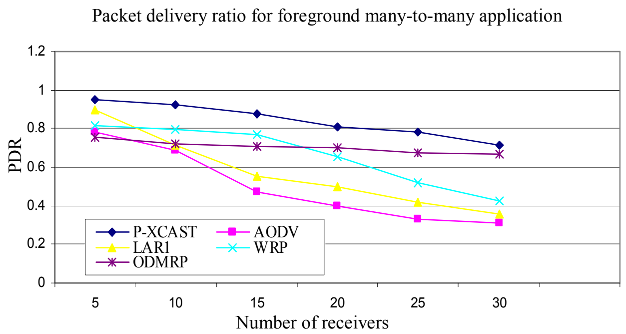

Figure 14. Packet delivery ratio for foreground many-to-many application.

GR is a measure of group communication performance equation 4, Figure 15 shows that P-XCAST has the highest GR that exceeded 0.8 for a group sizes of less than twenty receivers, while GR for all the other protocols was below 0.8 when the group size exceeded five receivers. This means that only P-XCAST would be suitable for achieving reliable group communications where at least 95% of the receivers in a group could receive the transmitted packets more than 80% of the time.

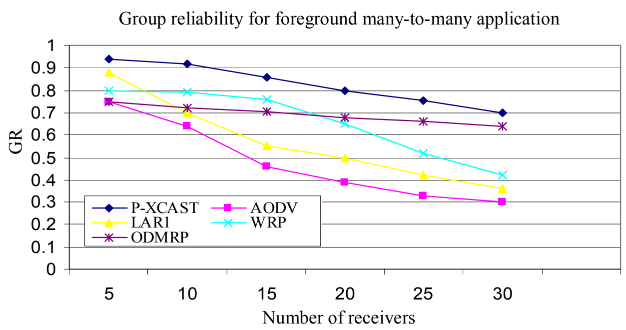

Figure 15. Group reliability for foreground many-to-many application.

4.2. The Effect of Using Many-to-Many Applications with Background Traffic on QoS Metrics

Background traffic from FTP sessions was active concurrently with foreground CBR traffic of 13.2 kbps in the following results Figures 16 and 20. This scenario was used to investigate the effect of background loads on the foreground many-to-many transmissions Figure 16 represents the effect of group sizes on link throughput for this scenario. P-XCAST link throughput was not affected for group sizes of less than twenty receivers; with the highest link throughput for all group sizes compared with AODV, WRP, LAR1 and ODMRP. The next best performer was WRP followed by LAR1 and AODV, while ODMRP performance was pretty constant regardless of the group sizes, though it was generally worse than the other routing protocols for small group sizes.

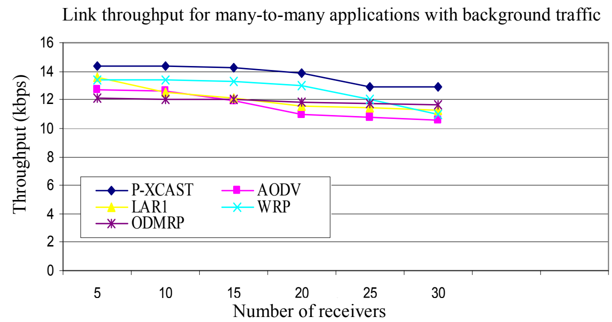

Figure 16. Link throughput for many-to-many applications with background traffic.

Figure 17 shows the effect of background trafic on many-to-many applications in terms of the average delay vs. the increase in group size. P-XCAST has lowest average delay values compared with AODV, LAR1, and WRP routing protocols. ODMRP performance is almost comparable to P-XCAST for group sizes of less than twenty receivers, while, LAR1 has the worst performance among all the tested protocols. The average delay experienced by foreground many-to-many transmissions for P-XCAST with background traffic was less than average delay values encountered by foreground applications Figure 12; as CBR has a higher periority than FTP applications so this leads to decrease the link traffic.

It is noted from Figure 18 that the tested results for P-XCAST, ODMRP and WRP routing protocols have the lowest values for jitter compared with AODV and LAR1. LAR1 had the largest jitter values. P-XCAST jitter values were within the QoS limits for all group sizes of less than twenty five receivers; while AODV, ODMRP and LAR1 jitter values increased rapidly with the increase in group size.

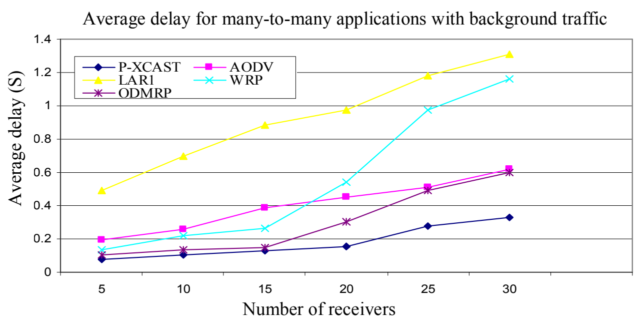

Figure 17. Average delay for many-to-many applications with background traffic.

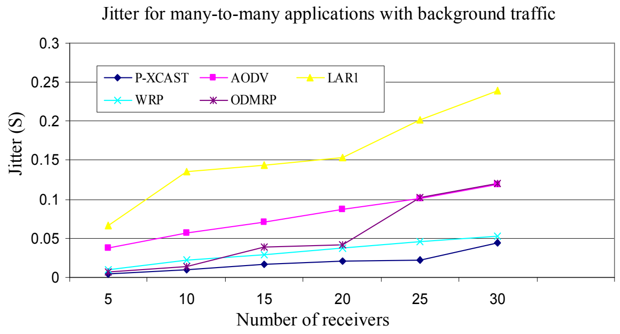

Figure 18. Jitter for many-to-many applications with background traffic.

Figure 19 shows that P-XCAST had the best PDR for different group sizes: better than 0.8 for all group sizes of less than twenty receivers, while LAR1, WRP, ODMRP and AODV all achieved PDR of less than 0.8 for group sizes greater than five receivers. Again, this indicates that P-XCAST had the lowest number of dropped packets, so P-XCAST is highly recommended to be used in real time applications.

There is an inverse relationship between GR and group sizes Figure 20. As number of receivers increase, the GR values degrades significantly for AODV and LAR1; while it is generally low for ODMRP and WRP. P-XCAST had the highest GR that exceeded 0.8 for a group sizes of less than twenty receivers, while the GR for LAR1 degrade rapidly above five receivers. In contrast, the group size has less effect on WRP and ODMRP performance but they do not meet the GR criteria.

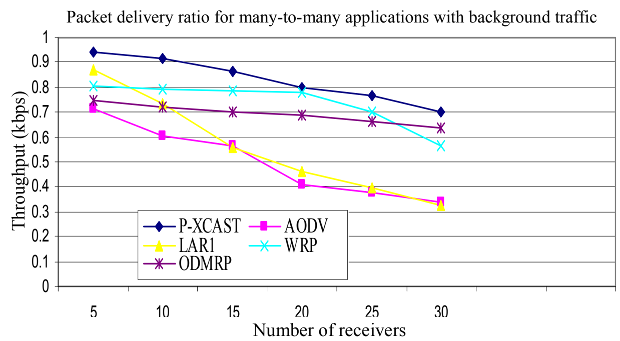

Figure 19. Packet delivery ratio for many-to-many applications with background traffic.

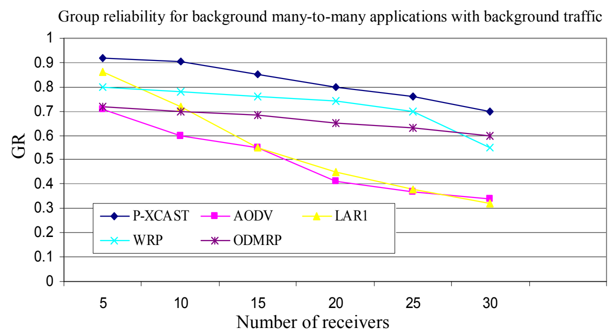

Figure 20. Group reliability for background many-to-many applications with background traffic.

5. Conclusions

In this paper, the proposed P-XCAST protocol was combined with a suitable group management protocol to support group-based many-to-many applications such as PTT. P-XCAST is based on the XCAST routing mechanism which had been adapted for group-based applications in MANETs. P-XCAST was evaluated using various QoS performance metrics including link throughput, average delay, jitter, packet delivery ratio and group reliability. The performance of various common MANET protocols, such as AODV, LAR1, WRP and ODMRP, was evaluated as well. These results showed the effectiveness of P-XCAST for various group sizes. The results showed that P-XCAST protocol was effective in reducing network overheads and improving QoS performance for group sizes of twenty receivers or less. The future work is to verify this protocol under different scenarios and to apply it towards dynamic topologies to support different mobility speeds, as well as to apply P-XCAST towards implementing new IP Multimedia Services subsystems (IMS). Security issues for P-XCAST will be studied and compared with other protocols security as P-XCAST has only one data packet instead of n-receivers data packet and this make it easier to control.

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