Multicast Video Performance Evaluation for Emergency Response Communications

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ABSTRACT

Group-oriented services including data dissemination, group calls and real-time video transmission are considered as an important application in public safety communications. The main interest is in one-way real-time video transmission from the hot spot to multiple recipients. This is important for efficient emergency response. The changing topology of the multi-hop communication links in a public safety environment makes routing and multicasting extremely challenging task. The purpose of this paper is to study the performance of wireless mobile ad-hoc networks with one-way multicast video traffic. To consider a realistic public safety scenario, the effect of extensive unidirectional links is investigated. The system performance study of various ad-hoc network configurations is done by simulations. For wireless multicast routing, the On Demand Multicast Routing Protocol is used. The performance results are compared with the requirements provided by Statement of Requirement document of standardization project MESA.

Keywords

Mobile ad-hoc networks, Edge effects, Random waypoint mobility model, Multicast routing, On-Demand Multicast Routing Protocol, QualNet network simulator, Unidirectional link

INTRODUCTION

Disaster recovery, search and rescue are typical scenarios where wireless ad-hoc networks could be deployed in the future. These networks are rapidly deployable and independent from any fixed infrastructure or centralized control. Besides voice and low bit rate data communications an ad-hoc network might be capable to support broadband applications too. The broadband applications such as high resolution video are not available in the traditional Private Mobile Radio (PMR) systems including TETRA and TETRAPOL. It is expected that video transmission among emergency workers might be critical for immediate response in terms of time, efficiency and human safety [1]. Real-time video dispatched from the firefighters on site gives an actual picture of the area under risk. It is extremely useful for distant evaluation, immediate tactical response and results in effective team coordination both in space and time.

The real-time services can be either point to point or point to multipoint. The need for point to multipoint communications in public safety is indispensable due to the high demands for team cooperation. In TETRA networks narrowband multicast services like group calls and Short Message (SMS) dissemination are commonly used. It is expected that ad-hoc networks would provide emergency workers with real-time multicast video by using wideband radio air interface. Video multicasting within a public safety hot spot would improve the situation awareness for the members of the emergency team. The safety of the firefighters acting as video feeders would be secured by allowing more and more emergency workers observing their activities. Firefighters enabled with multicast video receiving capabilities would offer rapid and efficient assistance to their colleagues that act as video feeders.

The usability of ad-hoc and mesh networking to support the emergency response is not a new concept for the public safety research community. In [2] a three-tier hybrid wireless mesh network architecture, the Extreme Network

System (ENS) is proposed and tested experimentally with medical emergency response applications. In [3] [4] a wireless mesh architecture including gateways with Wide Area Network (WAN) interfaces, wireless routers (mesh access points) and nomadic nodes is proposed for broadband internet access during large scale public safety operations. In the absence of WAN interfaces the proposed architecture allows for communication within the disaster area and might support delay sensitive applications due to the mesh backhaul formed among the wireless routers. Unlike [2] [3] [4] where a network hierarchy is introduced we use a flat ad-hoc network topology. The objective of this paper is to evaluate the performance of a delay critical application like the multicast video within a large scale public safety hot spot. The performance limits of mobile ad-hoc networks running delay sensitive and bandwidth demanding multicast applications would be identified by simulations. The degree of the performance degradation due to the impact of extensive unidirectional links would be studied as well. The Quality of Service (QoS) constraints collected in MESA user requirements studies [5] are compared with the simulation results.

It can be expected that the network topology within an emergency response hot spot is changing fast and unpredictably due to node mobility. This might result in discontinuous connectivity among the multicast group members in case a tree-based multicast routing protocol is used. To solve this problem a multicast routing protocol being able to enrich connectivity by providing redundant paths within the multicast group should be employed [6] [7]. The On Demand Multicast Routing Protocol (ODMRP) is a typical representative of these routing protocols. By using the concept of Forwarding Group (FG), ODMRP establishes multiple paths (mesh-based instead of tree-based routing protocol) between multicast senders and receiving nodes. This provides resilience against frequently changes of network topology that is common in emergency situations.

The unidirectionality is a common characteristic of ad-hoc networks that can be caused by different transmission power or background noise at either end of a link, signal interference or hidden terminal problem [8,9]. The performance degradation of ODMRP due to unidirectionality is demonstrated with respect to the density of nodes, the size of the multicast group and the number of senders multicasting video traffic. The simulation study is carried out with QualNet 3.9.5 network simulator [10] where the ODMRP library is available.

The structure of the paper is following. The QoS constraints for real-time video application elicited from user studies carried out by MESA are introduced and the simulations parameters are set. The simulation results are affected by the mobility model whose impact and parameter settings are discussed. The performance results with respect to the node density, the size of the multicast group and the number of multicast video feeders are provided. The results are evaluated, their importance in the context of public safety is pointed out and an idea for our future work is outlined.

PERFORMANCE METRICS AND QOS CONSTRAINTS

In public safety the key performance parameters for one way real-time video transmission are the ratio of delivered video frames and their one-way average end-to-end latency. To meet the user requirements frame loss up to 25% and end-to-end delay less than 500 ms are demanded [2]. For multicast traffic the following definition is used for the performance metrics related to the abovementioned QoS constraints:

Data packet delivery ratio: It is defined as the ratio of data packets delivered to the multicast receivers versus the number of data packets expected to be delivered. The total number of received packets by multicast receiving nodes is divided by the number of packets sent from multicast senders multiplied with the total number of multicast receiving nodes.

Average end-to-end delay of data packets: The average delay of data packets from application layer of multicast source to application layer of the multicast receiving nodes is recorded. This metric contains the queuing and protocol processing delay as well as transmission and propagation delay. The discarded packets are not considered in the calculation.

SIMULATION SET UP

All the simulations share some common set up parameters in the different layers of the protocol stack which are summarized in the following:

The simulation scenarios include multicast video application testing with IEEE 802.11b PHY at 11Mbps. Lower physical bit rates were failed to support the QoS constraints. The transmission range of the network nodes can be easily obtained by executing point to point simulations. The maximum distance with high link quality meaning that all packets are received without errors was found to be 310 m at 11 Mbps.

If N nodes are placed within a square area of size S m^2 and the transmission range of each node is R m, the expected number of neighbors per node is:

$$\mathrm{k}_{\exp} = \frac{\pi R^2}{S} N \qquad (1)$$

Equation (1) implies that all the nodes in the network would increase their average number of neighbors proportionally to the square of their transmission radius. However this is not the case for the nodes placed near the boundaries of the area. Indeed, the coverage area of these nodes is extended beyond the limits of the deployment area where no other nodes are placed. This phenomenon is referred as the edge effect in [12] and its consequences are discussed in the next section.

Our simulation scenarios consist of forty nodes placed randomly within a square area. The size of the area determines the density of nodes which affects the performance of the protocol. Namely, more dense topologies result in higher data throughputs at the expense of larger control overhead due to the mesh nature of the protocol.

The free space path loss (attenuation proportional to $1/r^2$) for short distances and two-ray path loss (attenuation proportional to $1/r^4$) for distances larger than a critical point (breakpoint) are used. The value of the breakpoint depends upon the wavelength and the antenna heights of transmitter and receiver.

In emergency response the deployment of equipment with different radio capabilities (e.g. transmission power and sensitivity) is quite common. The transmission power levels of man-pack and vehicular radios can differ up to 10 dB [11] and even radios of the same type are constructed by different manufactures. Furthermore the noise level inside the hot spot might vary with space and time. The disparity between the transmission power levels among the network nodes can be the reason for extensive unidirectional links. To create unidirectional links the two-power model is used as this model results in a high degree of link unidirectionality [11]. In particular, every node is assigned a transmission power value of either 15 dBm or 7.5 dBm with equal probability. Hereafter, a network with homogeneous power assignment equal to 15dBm is referred as an ideal scenario while a network with heterogeneous power assignment is referred as a real scenario. It is expected that the existence of more unidirectional links in the real scenario compared to the ideal would degrade the performance of ODMRP.

For the mobility study, the random waypoint (RWP) mobility model is used. With this model the number of broken links increases compared to the group mobility model and the mesh-based nature of the ODMRP becomes more evident. The RWP mobility model was recently questioned for simulation work because it suffers from the speed decay phenomenon [13]. The set up parameters for the mobility model used in our simulations are discussed in the next section.

The simulator uses IEEE 802.11 model for the MAC layer. Control messages and data packets are broadcasted under ODMRP but there are unicast transmissions as well (e.g. active acknowledgments). To avoid the use of virtual carrier sensing (VCS) at the MAC layer [14] and maximize the throughput performance, the Request to Send (RTS) threshold is set sufficiently high. Regarding the soft state timers of ODMRP some typical values are used. The route refresh interval equals 3 s and the FG timeout is 12 s.

Constant bit rate UDP traffic is used for the data in order to simulate video transmission. The UDP payload size is 1344 bytes and contains a twelve-byte Real-Time Protocol (RTP) header. The pause time between the generations of each video packet is 30 ms. Therefore the datarate of the simulated video application equals 355 kbps.

MOBILITY MODEL SET UP PARAMETERS

To model mobility in a large scale public safety hot spot involving both pedestrians and vehicles the RWP mobility model could be a reasonable choice. According to this model every node selects randomly a destination point and moves to it with a constant speed uniformly distributed within the interval $[V_{min},V_{max}]$. As soon as the node reaches the destination, it remains static for a predefined amount of time t_p that is common for all the nodes in the network. According to [3] one has to be extremely careful about the parameter settings of RWP mobility model and especially for the V_{min}. For instance when the minimum node speed equals zero more and more nodes would be trapped to low speeds and the average instantaneous network velocity would be gradually decreased. As a result the calculation of performance metrics in the form of an average over an arbitrary set of time would be inaccurate. For this purpose a potential solution could be to set the minimum node velocity to a non-zero value and study the network performance after the so-called warm-up phase [13, 15]. Figure 1 depicts the average instantaneous network velocity under RWP mobility model as a function of the simulation time that equals 1000 s. The instantaneous node velocity is monitored every second and the average speed over the forty network nodes is calculated. The velocity of each node is uniformly selected between 1 m/sec and 19 m/sec. The pause time is set to 50 s to model a network with moderate mobility attribute. The different curves depicted on Figure 1 correspond to different expected density of nodes as it is calculated by (1) and they are average values over more than hundred runs.

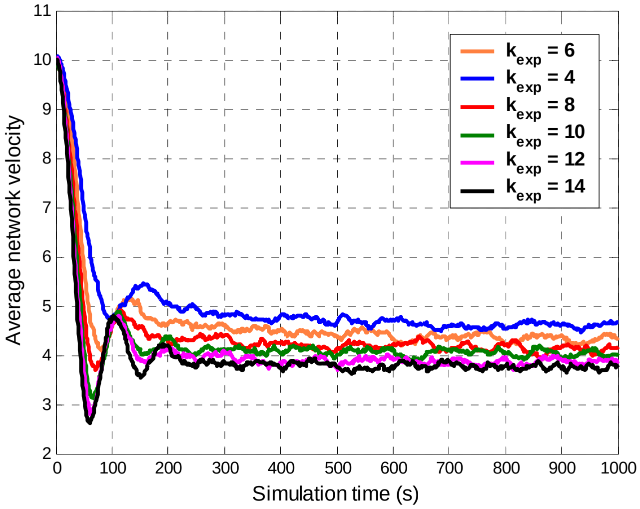

Figure 1. Instantaneous average network velocity versus simulation time for different expected number of neighbors.

From Figure 1 one can observe how the average instantaneous node velocity is not decreased over the simulation time but rather it is stabilized after the half of the simulation. Therefore a reasonable assumption would be to let the network reach its steady state at 500 s in the context of the average speed and evaluate the multicast video performance during the second half of the total simulation time.

Secondly, from Figure 1 one can also observe that the denser is the network structure, the lower becomes the average network velocity. According to (1) increasing expected number of neighbors corresponds to decreasing size of deployment area for fixed number of nodes. For smaller areas the fraction of time a node moves compared to the time it remains static (recall that the pause time was set to a non-zero value) is decreased. Therefore denser node distributions would reduce the mobility attribute of the network in case the total number of nodes is constant.

The validity of the expected number of neighbors calculated by (1) is now discussed. Figure 2 shows the instantaneous average number of neighbors per node over the simulation time and for homogeneous power assignment. Recall that the transmission range at 11 Mbps and for transmission power level equal to 15 dBm is 310 m in QualNet. The curves are an overage over hundred runs and the number of neighbors per node is evaluated every second. The network moves according to the RWP mobility model with the parameter settings given above.

As one can see from the Figure, at the beginning of the simulation the actual number of neighbors is always smaller compared to the expected value calculated by (1). Indeed, since the nodes are initially uniformly distributed within the square area the impact of the edge effect is severe. However the instantaneous average of neighbors per node seems to increase with time and possibly converge to the expected value. This phenomenon is a repercussion of the RWP mobility model too.

In [15] it is proved analytically that the initial node distribution within a square area which is usually uniform is different from the node distribution after the movement of the nodes according to the RWP mobility model. In particular the nodes tend to spend more time within the regions that are close to the centre of the area and less time towards the boundaries of the area. The simulated results presented on Figure 2 are consistent to the analytical results proved in [15]. A network moving within a square area and according to the RWP mobility model tends to be concentrated towards the middle of the area as the simulation evolves. Therefore the average number of neighbors per node would be increased with time. Recall that in our scenario we reduce the size of the deployment area to increase the density of the nodes. As a result the edge effect becomes more persistent for dense node distributions. This is the reason that for dense topologies the average number of neighbors remains lower than its expected value.

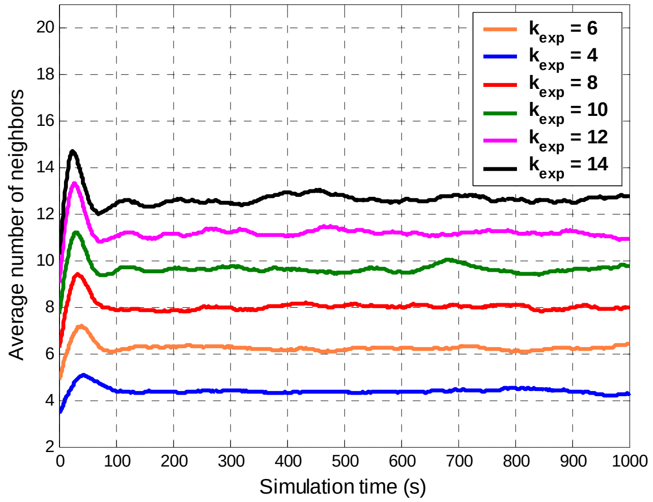

Figure 2. Instantaneous average number of neighbors per node versus simulation time for different expected number of neighbors and homogeneous transmission power assignment.

Figure 3 illustrates how the instantaneous average of neighbors per node is further reduced by applying the two-power model. Every node would transmit with either 15 dBm or 7.5 dBm with equal probability. We note that for transmission power level equal to 7.5 dBm at 11 Mbps the transmission range in QualNet equals 180 m.

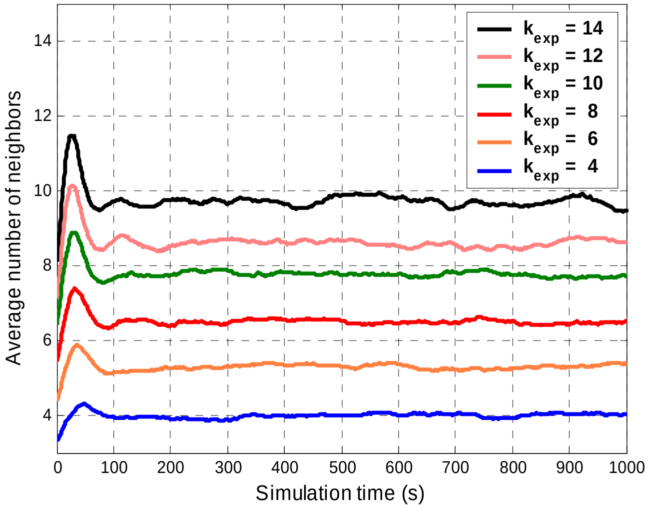

Figure 3. Instantaneous average number of neighbors per node versus simulation time for different expected number of neighbors and heterogeneous transmission power assignment.

SIMULATION SCENARIOS AND RESULTS

Node density

In the first simulation experiment the performance of video application with respect to the network density is tested both for the ideal and real scenario. Recall that the ideal scenario is characterized with homogeneous power assignment while the two-power model is applied for the real scenario. To vary the node density the size of the deployment area is modified while the total number of nodes remains constant. Based on (1) the size of the area is calculated for different expected number of neighbors. For the real scenario the size of the area is determined based on the higher transmission power. As a result the real and the ideal scenario are characterized by the same density of nodes. However the actual average number of neighbors is lower for the real scenario as one can deduce by comparing Figures 2 and 3.

As the node structure becomes more compact the path redundancy between multicast senders and receiving nodes is increased. Therefore the data delivery ratio becomes higher. For the same reason the impact of extensive unidirectional links in the real scenario should be eliminated for dense configuration of nodes. On the other hand a dense node distribution results in high network congestion level since many nodes becomes members of the FG and broadcast data and control packets. Additionally a network node has to compete with many others to achieve medium access. Therefore large average end-to-end delay values would be incurred for dense networks.

The packet delivery ratio and the corresponding end-to-end delay values are presented in Figure 4 and Table 1 respectively. Two multicast senders and ten multicast receiving nodes all belonging to the same multicast session are selected randomly within the network. The simulation time equals 1000 s and the generation of multicast traffic starts at the middle of the simulation time. Each point on Figure 4 is an average over 10 runs with different initial positioning of nodes and RWP mobility patterns.

As one can observe on Figure 4 the performance degradation of the video application in a real scenario compared to the ideal scenario is more severe for sparse network graphs. As the node density increases the redundant paths within the multicast group are amplified and the effect of many unidirectional links in the real scenario is eliminated. For dense network configurations like eight neighbors per node, the two video application flows meet the QoS constraints both for the ideal and real scenario.

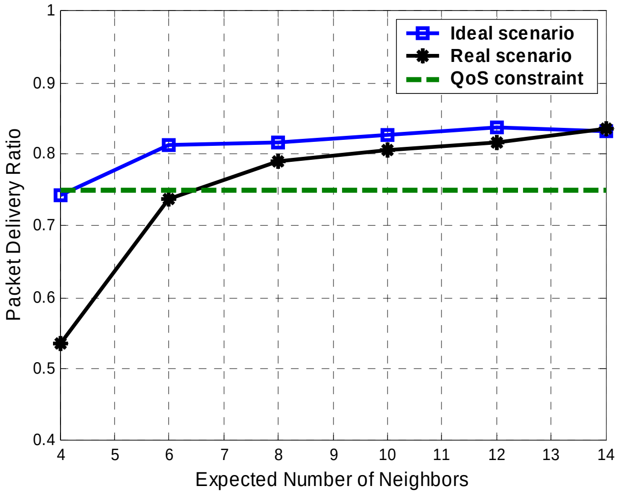

Figure 4. Packet delivery ratio of two video applications versus the expected number of neighbors per node.

Table 1 shows that the average latency of data packets in the real scenario is significantly smaller compared to the ideal scenario. Indeed, many control and data packets are dropped along routes including unidirectional links. Therefore the overall control and data forwarding overhead is significantly reduced for the real scenario.

The data forwarding overhead is defined as the total number of data packets forwarded divided by the data packets delivered to the multicast receiving nodes. In the ideal scenario more nodes become members of the FG and broadcast data packets. Therefore the network suffers more from congestion. Additionally the actual number of neighbors is larger for the ideal scenario as one can deduce by comparing Figures 2 and 3. As a result the channel contention becomes more persistent. Due to these factors the measured average end-to-end delay is higher for the ideal scenario.

	Average Number of neighbors per node					
	4	6	8	10	12	14
Delay (ms) real scenario	23	34	44	75	93	90
Delay (ms) ideal scenario	109	306	292	361	370	334

Table 1: Average end to end delay of two video applications for various densities of nodes

Multicast group size

ODMRP is efficient for large multicast groups with few multicast senders, light network load and homogeneous power assignment [6]. The validity of this property is now tested with heavy video applications.

Two typical values were selected for the node density in our simulations. Figure 4 illustrates that six and eight neighbors are the minimum values satisfying the QoS constraints for the ideal and real scenario respectively. We use these two values for the node density and test how the size of the multicast group affects the protocol performance.

Figure 5 presents the packet delivery ratio of two video flows for varying number of multicast group size. Each point is an average over ten runs. As one can see the increase in packet loss is relatively small as the size of multicast group grows. This means that the protocol scales well with the number of multicast receiving nodes. In Table 2 the average end-to-end delay is given.

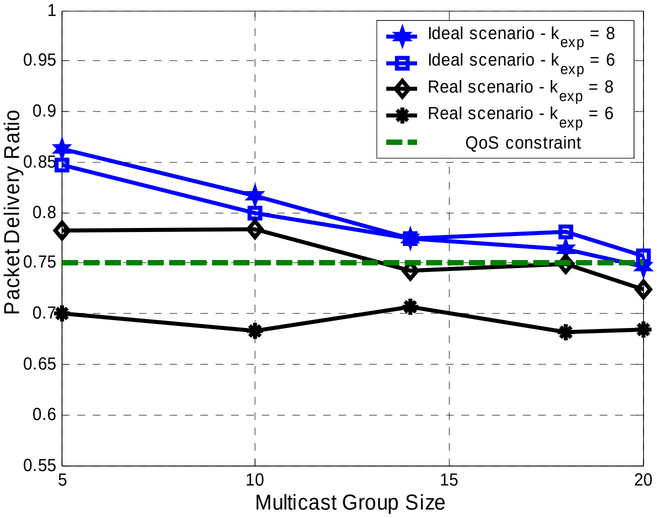

Figure 5. Packet delivery ratio of two video applications versus the size of the multicast group.

The protocol becomes more efficient for larger multicast groups meaning that the control and data forwarding overhead per node is reduced [6]. However the overall control and data overhead is increased. For instance, the number of ODMRP Join Replies (JREP) is grown proportionally to the number of multicast receiving nodes. The size of FG is also increased as more nodes join the multicast session. Especially for dense node distributions where the FG members are located close to each other the network congestion becomes higher and the channel contention more intense. For this reason the video application fails to meet the delay constraint in an ideal environment with dense configuration of nodes (k_{exp}=8 or more) and large multicast group. On the other hand, the protocol overhead is significantly smaller and the channel contention less persistent in the presence of extensive unidirectional links. As a result the measured delay in the real scenario is again smaller compared to the ideal scenario. Figure 4 illustrates that the effect of unidirectional links in the context of data delivery ratio is alleviated for dense node distributions. Figure 5 shows that large multicast groups within dense networks bring the performance of the two scenarios close to each other. However, the data delivery ratio in a real scenario with sparse network topology is unrelated to the multicast group size and fails to meet the QoS constraints.

	Size of Multicast Group				
	5	10	14	18	20
Delay (ms) ideal scenario 8 neighbors	102	319	460	552	553
Delay (ms) ideal scenario 6 neighbors	103	250	374	453	433
Delay (ms) real scenario 8 neighbors	24	56	96	109	151
Delay (ms) real scenario 6 neighbors	23	32	45	64	59

Table 2: Average end-to-end delay of two video applications for different size of the multicast group.

Number of multicast senders

As the next step the protocol performance is tested with respect to the number of multicast senders. So far only two video feeders were considered but in a public safety scenario the need for devices transmitting real-time video is usually higher. In an ideal scenario with light network traffic load ODMRP shows robustness to the number of multicast senders [6]. However the property of ODMRP to build per-source meshes increases the control overhead proportionally to the number of senders. This might degrade the overall performance when the applications running within the network are heavy. Figure 6 presents the packet delivery ratio for increasing number of video applications when the size of multicast group is fixed to 10 nodes. As one can see in case more than two sources multicast their traffic within the network the performance degradation is severe for every node density and for both kinds of scenarios.

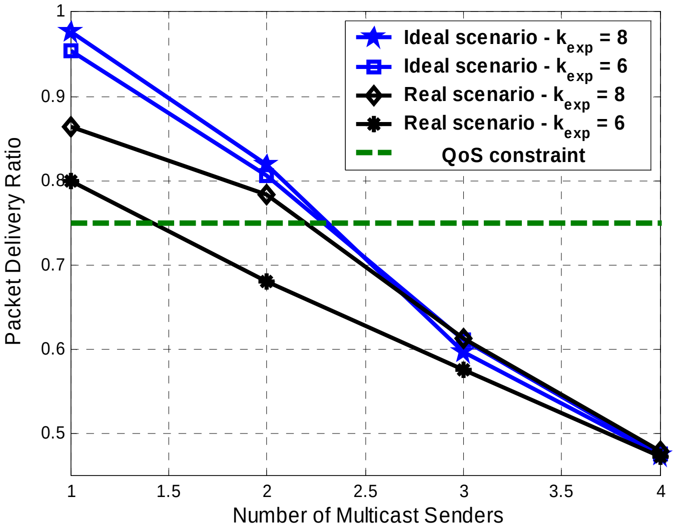

Figure 6. Packet delivery ratio for increasing number of video flows.

CONCLUSION

Dispatching real-time video from the affected area extremely improves the efficiency of the emergency response and increases the safety of the firefighters deployed within the hot spot. In this paper we tested the performance of multicast video application within a mobile ad-hoc network and against typical public safety user requirements. Two scenarios with homogeneous and heterogeneous transmission power assignment were considered so as to reflect the existence of different radios in a public safety operation. The existence of different transmission power levels gave rise to extensive unidirectional links. The multicast video performance was simulated for both scenarios and the performance results were compared. Before the actual simulation study the effect of the RWP mobility model to the average network velocity and the average number of neighbors were investigated by simulations. The velocity parameters and the generation time of the multicast traffic were set accordingly. The protocol performance was tested after the so-called warm-up phase of the network to acquire reliable results.

For the simulation study the ODMRP was selected due to its inherent resilience against mobility and unidirectional links. The simulation study was conducted with IEEE 802.11b PHY at 11 Mbps within an ad-hoc network of forty nodes. Lower datarates were failed to satisfy the public safety QoS requirements for one-way real-time video communication. The system performance was found to be dependent on the physical bandwidth, the unidirectional links, the size of the multicast group, the number of multicast video feeders and, the expected density of nodes; the size of the deployment area. In case the distribution of the nodes was dense the existence of radios with different transmission power levels did not degrade the system performance. As the node density was increased the connectivity within the multicast group was enhanced eliminating the effect of unidirectional links. In addition the existence of many unidirectional links reduced the overall control and data forwarding overhead making the average delay of the data packets smaller. The multicast group size was found to affect mainly the average latency of the video applications. When a large number of nodes joined the multicast session the robust mesh structure among the multicast members guaranteed a rather small decrease in the data delivery ratio. However the simultaneous increase in the control and data forwarding overhead might make the average latency of the video application unacceptable. Finally, the performance was rather poor for more than two multicast senders and for both scenarios no matter how dense the network was.

FUTURE WORK

To improve the performance in sparse networks with unidirectional links a non-conventional routing protocol should be applied. The ODMRP-ASYM routing protocol with robustness to unidirectional links is presented in [9]. The authors of this paper implemented ODMRP-ASYM in QualNet simulator and they showed that packet delivery improvement up to 15% can be achieved compared to conventional ODMRP. However, the performance degradation as more nodes becomes multicast senders is severe even for networks with homogeneous power assignment. In addition for dense node distributions the average end-to-end delay was rapidly increased especially in the presence of many multicast receiving nodes.

To support more video flows at the same time the issues of excessive packet loss and unacceptable end-to-end delay need to be resolved. To meet the public safety needs in such cases we plan to investigate the multicast video performance within a mesh network architecture. A fraction of nodes having both wireless and wired interface (e.g. backbone of gateways) would increase the resilience of the network because of the stable wired links. Multiple paths within the multicast group would support load balancing and decrease the packet loss. In addition the rapid transmission of data packets through the wired part of the network would support delay sensitive applications in large scale public safety networks. However many open issues like optimal clustering of the network nodes and topology control algorithms for distributed management needs to be resolved first.

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