User and Network Level Evaluation of VoIP over Emergency Ad-hoc Networks

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ABSTRACT
In this paper, a performance evaluation of VoIP over ad hoc networks in emergency scenarios is presented. In these scenarios, emergency workers need to act and communicate with each other in disaster areas that significantly differ from the usual scenarios found in the literature. Obstacles placed in the network area pose limitations to nodes' mobility and signal propagation with considerable impact on the voice quality. Simulations based on the Human Obstacle Mobility model (HUMO) have been performed in order to quantify the performance degradation due to the presence of obstacles. In doing so, network performance metrics and human perception metrics based on the extended E-model have been used. It is shown how different voice codecs behave in different obstacle coverage and mobility scenarios. Furthermore, MOS distribution is approximated. Results underline the importance of simulation environment to the derivation of realistic results concerning VoIP quality.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Wireless communication, C.2.2 [**Network Protocols**]: Applications

General Terms
Measurement, Performance.

Keywords
VoIP evaluation, emergency communications, ad-hoc networks, human mobility model

1. INTRODUCTION
Emergency communications is a field that has gained particular attention lately since it is a vital part of advanced emergency management systems. The success and the effectiveness of response to daily as long as extreme emergency situations depends on the extent critical information regarding the incidents is gathered, processed and disseminated according to certain chains of hierarchies and authorities. Civil protection agencies worldwide pay continuous efforts to improve their telecommunication infrastructures and adopt the latest advances ICT industry can offer. Coordination of multiple types of emergency workers (policemen, firemen, paramedics etc.) is strongly affected by the available networking capabilities. It is a common belief that in case of emergency the best possible response cannot be achieved without secure and reliable communications. Furthermore, the emergency response plans are designed according to what the available telecommunication infrastructure can offer. Emergency communications play a key role to the management of resources and provide agencies with crucial information that affects decision making.

The present work focuses on extreme emergency situations in which groups of emergency workers need to act on-site. In cases like these (earthquakes, floods, fires etc.) there is need for real-time peer-to-peer wireless communication among individuals of either the same or of different groups, authorities or degree. Communication must be reliable and error-resilient. Common practice has shown that voice communication is the most preferable solution because it is quick, direct and effective, especially when officers give orders to personnel or when workers need to report the current conditions or ask for reinforcements. Although still widely used, analog wireless equipment tends to become obsolete and digital communication solutions are adopted from emergency response groups, like amateur radio groups that use D-Star technology. Within the context of IP networks, Voice over IP (VoIP) is the most up-to-date solution for voice communication in the examined scenarios. Thus, given the ad hoc nature of the way emergency workers act and communicate, VoIP performance over ad hoc emergency networks is an important issue that needs to be investigated.

The majority of works on VoIP performance over wireless networks does not take into account constraints of the area such as obstacles and mobility speed. Obstacles are almost always present in disaster areas where emergency workers are called to act. Obstacles have a deep impact on wireless communication between workers as, apart from the signal attenuation they introduce, they also affect the resulting network topology and the way workers move. The aim of the present work is to evaluate these phenomena and their impact on voice quality by means of simulation. Objective performance metrics and subjective metrics

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based on human perception of speech quality have been used. The basis of the simulations is a human mobility model that incorporates the effect of obstacles briefly described before. It is shown that without taking into account the effect of the obstacles placed in the network area, optimistic results are produced.

The rest of the paper is organized as follows: In Section 2, previous work on performance evaluation of VoIP over wireless networks is presented. In Section 3, the human mobility model is described. Simulation results are presented and discussed in Section 4. Finally, Section 5 concludes the paper.

2. PREVIOUS WORK

VoIP Transmission over ad-hoc networks has received particular attention in the last years. The initial development of 802.11 family of protocols was mainly combined with wireless access to the internet and TCP traffic. Delay-sensitive applications such as real-time audio/video transmission posed new challenges that motivated scientific community to provide solutions mainly based on MAC layer mechanisms which sometimes led in protocol amendments. As 802.11 standards are dominant in ad hoc networking and given the fact that peer-to-peer VoIP communication in such networks is a primary application, performance evaluation is important. There are many works in the literature that try to capture the way intrinsic characteristics of ad hoc communication and involved protocols affect speech quality. The authors in [1] examine the impact of ad-hoc routing protocols (AODV, OLSR) on the perceived voice quality. In [2] a joint approach is proposed in order to manage variability of network topology and channel behavior by jointly selecting the transmission and adjusting the playout delay, while [3] presents a power-aware ad-hoc routing protocol and examines its impact on the voice quality. The aforementioned works highlight the sensitivity of VoIP performance in network-layer-related impairments.

The dependence on wireless channel characteristics such as fading is evaluated in [4]. The distributions of PER and MOS under different fading conditions are derived via simulation. In [5], there is a calculation of an upper bound for capacity. It is concluded that although G.711 codec is designed for better voice quality, G.729a can offer higher capacity. Capacity proves to be very sensitive under the strict delay constraints required in voice transmission.

Protocol capabilities that efficiently handle VoIP traffic have always been a field of research. In [6], a signal-based method to evaluate the impact of background traffic in VoWLAN is presented. EDCA method is used as a strong candidate to DCF and PCF. Moreover, there is a method for improved detection of critical conditions. Authors in [7], suggest a technique for measuring one-way delay and they investigate how EDCA parameters affect delay. A dual-queue system with strict priority queuing is applied in [8]. Finally in [9], authors show that a packet multiplexing-multicasting system combined with header compression can alleviate the two major challenges in VoWLAN: low capacity and low performance in the presence of other traffic types.

Unlike the previous studies, our study examines MANETs in emergency scenarios, where an emergency working team (e.g. police, firebrigade) moves to an area in order to manage the emergency event. In this scenario, the nodes have the ability to bypass the obstacles that can be present in the area. Emphasis is given on the impact of the obstacle coverage and the mobility of the MANET nodes on both user and network level performance for different voice codecs by calculating MOS through the extended E-Model.

3. THE HUMAN MOBILITY MODEL

The Human Mobility Obstacle (HUMO) model targets to realistically simulate mobile ad hoc networks that are consisted of human-operated nodes deployed in areas where obstacles are present. Primary examples of such scenarios are emergency situations like earthquakes, fires, etc, and military operations, where the nodes consisting the mobile ad hoc network are firemen, medics, policemen, soldiers, etc, operating in an area where obstacles are indispensable part of the scenery.

In the HUMO model the nodes move their way around the obstacles in the network deployment area according to a natural and realistic way. If there is an unobstructed line of sight connecting the current node's position with its destination, the node follows this direct line to get to the desired destination. If there is an obstacle in the way, the node sets as its next intermediate destination the vertex of the obstacle’s edge directly visible that is closest to the destination and repeats the same process all over again with starting point its initial position and destination the chosen vertex. This is repeated until an unobstructed direct line until the current destination is found. The whole process is recursively executed until the destination is reached. Apart from restricting the node movement, obstacles in the HUMO model also pose limitations in the signal propagation. A complete description of the HUMO mobility model can be found in [10].

4. SIMULATION RESULTS

In this part, the performance evaluation of VoIP communication in emergency ad hoc wireless networks is presented. Given the fact that generic network performance metrics do not precisely depict the performance of the system in accordance with the users' perception of quality of speech, metrics that represent subjective human criteria are more appropriate. Emphasis is given on how three different voice codecs, namely G.711, G.729A and G.723.1, perform under different obstacle configurations and mobility scenarios.

Simulations were conducted using the network simulator ns-2 [11]. The HUMO model that is implemented in ns-2 was used for simulating nodes' movement in the presence of obstacles. It is worth mentioning that in the absence of obstacles HUMO reduces in the Random Waypoint (RWP) model. The VoIP module available at [12] was used for simulating VoIP functionalities in ns-2. It incorporates multiple voice codecs, frame aggregation and a model for simulating MOS as user's perceived quality. It also has integrated features for data collection and analysis [13].

Nodes were placed in an area of 500x500 m^2. Nodes operate using the IEEE 802.11 standard and their range is set at 250 m. 10 tcp connections of about 5 kbps each, have been used as background traffic. AODV was the routing algorithm in use. In order to evaluate the impact of obstacles in the VoIP communication between nodes, obstacles were placed in the simulation area covering 10%, 30%, 50%, 70% and 90% of the it. Results were also compared with unobstructed communication scenario. Nodes' speed varies between 1 and 20 m/sec in order to include both pedestrian and vehicular speeds, since emergency workers may either move on foot or by vehicles. The simulation setting is summarized in Table 1.

Table 1. VoIP Simulation Parameters

Simulation Parameters	
Number of nodes	50
Network area	500x500 m^2
Node range	250 m
Routing algorithm	AODV
Voice codecs	G711, G729A, G723.1
Obstacle coverage	0%, 10%, 30%, 50%, 70%, 90%
Maximum node speed	1, 2, 5, 10, 20 m/sec

Figure 1 shows the impact of obstacles on average MOS per talkspurt for three different voice codecs. Performance degradation is evident when compared to the unobstructed communication scenario even when obstacles cover only 10% of the simulation area. The variations observed when obstacles cover between 10% and 70% of the simulation area are explained by the fact that the presence of obstacles increases node density and thus assist neighboring nodes and route discovery. On the other hand, the interference is also increased causing packet loss and higher delay. This is why further performance degradation is observed in the case 90% of obstacle coverage.

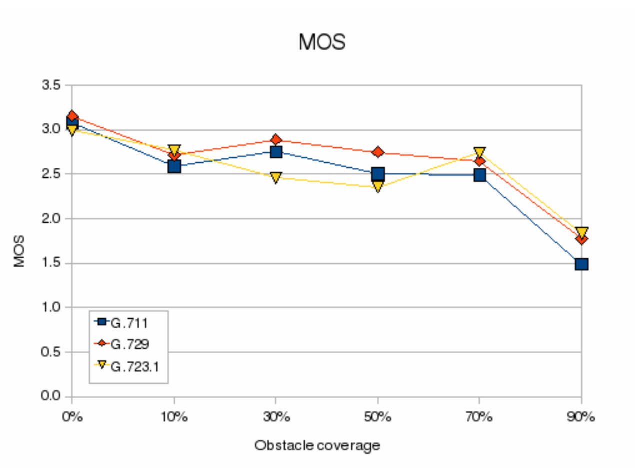

Figure 1. MOS versus obstacle coverage

Figures 2 and 3 present typical network performance metrics. Figure 2 shows frame delay versus obstacle coverage. Delay variations are observed for the reasons described previously. G.711 seems to be the most obstacle-prone codec since after 50% of obstacle coverage delay dramatically increases. In Figure 3, frame delivery ratio versus obstacle coverage is depicted. The number of lost frames increases with obstacle coverage, especially in the case of 90% obstacle coverage. Both G.729A and G.723.1 perform better compared to G.711 in terms of frame delivery ratio.

Node mobility is also an important characteristic of the examined ad hoc network. As seen in figures 4 and 5, VoIP performance in obstructed scenario is worse than in the unobstructed one in terms of MOS for every node speed. The only difference is that in the absence of obstacles the behavior of all the three codecs is almost the same as speed increases. Sometimes mobility helps network performance and this justifies the observed variations in MOS.

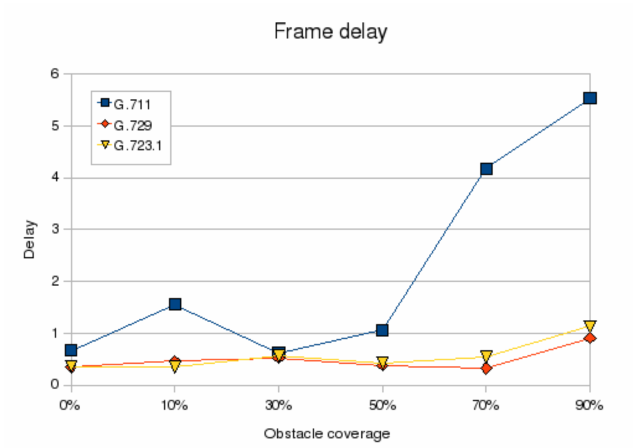

Figure 2. Frame delay versus obstacle coverage

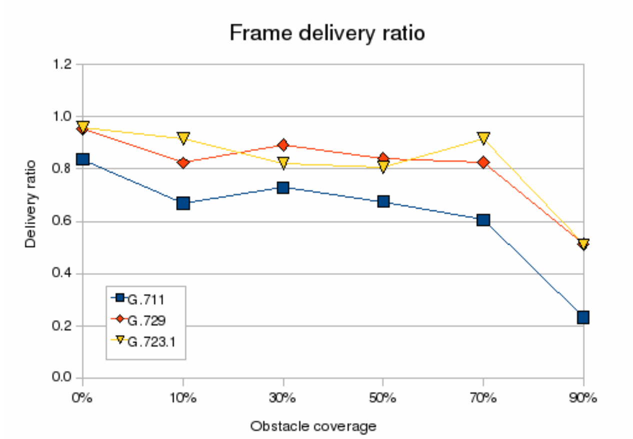

Figure 3. Frame delivery ratio versus obstacle coverage

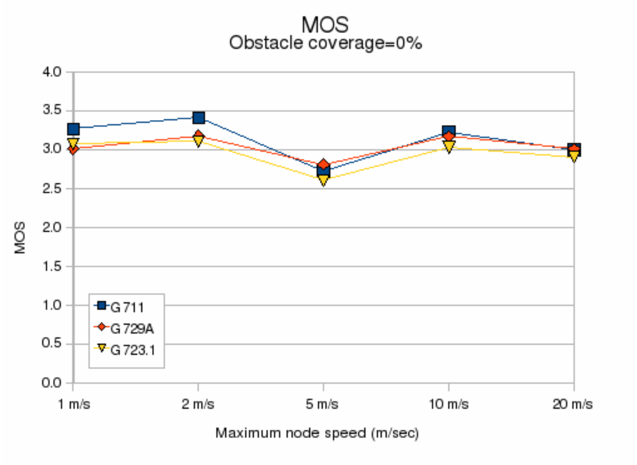

Figure 4. MOS versus node speed for unobstructed communication

So far performance metrics based on averaged values were presented. However, when it comes to real-time delay-sensitive communication such as VoIP, the performance on session basis through time is crucial. Averaged metrics sometimes fail to describe actual system's behavior. Distribution of MOS over a VoIP session is more indicative and further highlights differences between the three codecs.

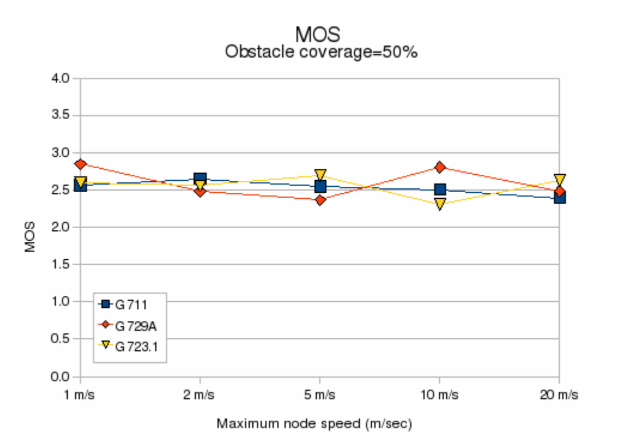

Figure 5. MOS versus node speed in obstructed communication

Figures 6-8 depict MOS distribution for obstructed and unobstructed scenarios for G711, G729A and G723.1 respectively. 50% obstacle coverage was chosen for the obstructed case. As shown in figure 6, G711 can achieve high quality VoIP communication, higher than G729A and G723.1 for almost 80% of the duration of a session. However, it is more prone to spikes that limit quality to level 1 in terms of MOS. The basic impact of obstacles is that the number of those spikes is doubled. G729A and G723.1 perform more all less the same in the presence of obstacles.

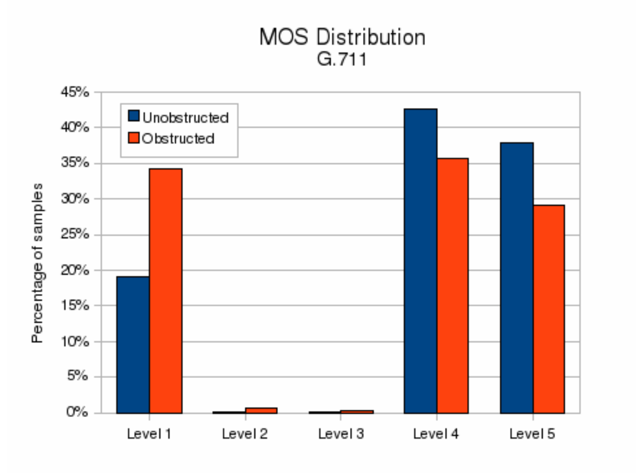

Figure 6. MOS distribution for G711 codec over a VoIP session

The only difference is that in G.723.1 higher transition to level 1 is observed. Both codecs are characterized by the fact that the majority of samples are concentrated in level 3. Spikes to level 1 are more rare than in G.711 case. As a result, despite the high concentration of samples at levels 4 and 5 in G711, variance due to spikes is increased and so G.711 sometimes performs worse than the other two codecs in terms of averaged values. In general, communication in the presence of obstacles results in MOS distributions shifted towards lower level of perceived speech quality.

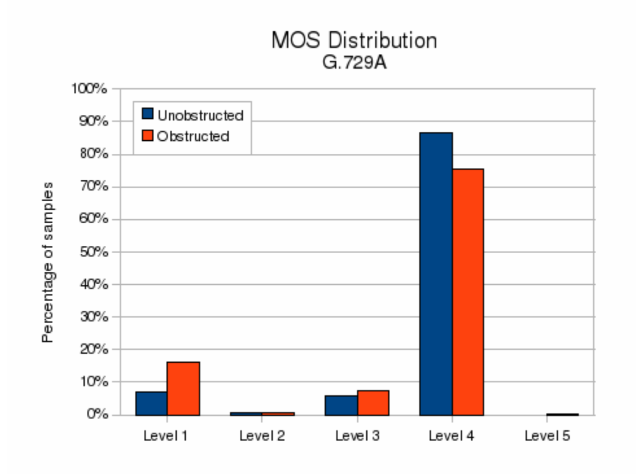

Figure 7. MOS distribution for G729A codec over a VoIP session

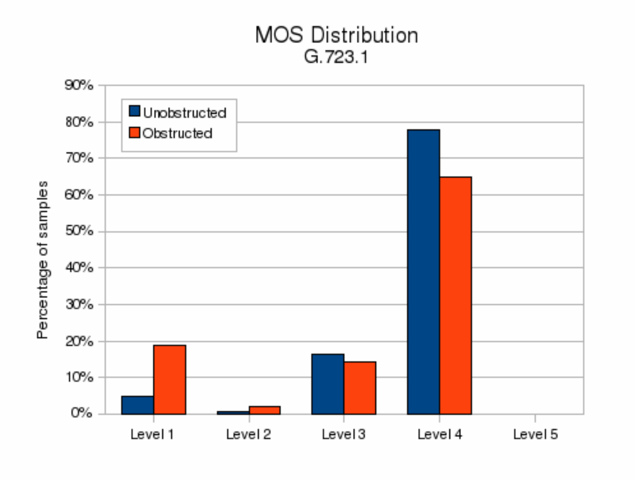

Figure 8. MOS distribution for G723.1 codec over a VoIP session

The derivations of the previous distributions are depicted in Figure 9 in which MOS performance versus time for a randomly selected VoIP session in the presence of obstacles is presented. Indeed, G711 achieves higher MOS for certain time periods and it also suffers from spikes. Using G.729A lower MOS is observed while at the same time MOS variance is significantly decreased which is in accordance with figure 7. G.723.1 achieves even lower values of instantaneous MOS combined with higher variance. Spikes are not so often as in G711 case-which is also verified through a comparison between figures 6 and 8- but they contribute to the performance deterioration.

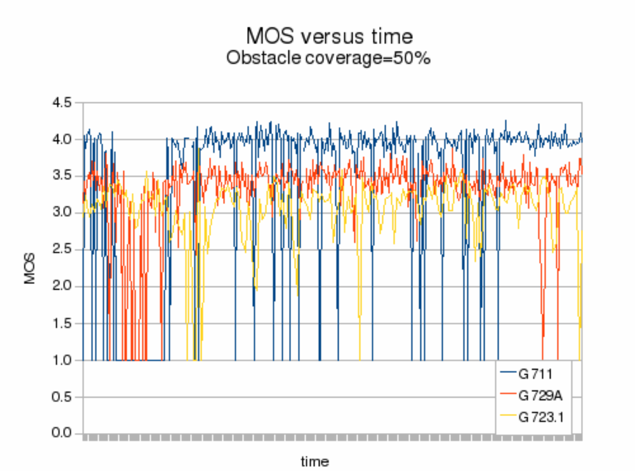

Figure 9. MOS versus time over a VoIP session

5. CONCLUSIONS

In this work, a VoIP performance evaluation over emergency ad hoc networks was presented. The main characteristic of the set of simulations performed is the adoption of the Human Obstacle Mobility Model which is suitable for simulating node movement in geographically restricted areas in the presence of obstacles. The model is ideal for simulating emergency ad hoc communication networks as it incorporates the impact of obstacles on mobility patterns, network topology and radio propagation.

The performance evaluation was mainly based on the obstacle coverage, i.e. the percentage of network area covered by obstacles. Three different voice codecs (G.711, G.729A, G.723.1) have been used and the effect of node speed was also taken into account. Apart from usual network metrics such as frame delay and frame delivery ratio, user-level metrics like MOS were also used. It was shown that VoIP quality decreases as obstacle coverage increases. A remarkable difference in delay performance is observed in the use of G.711 codec, especially in highly obstructed scenarios. The performance degradation due to obstacles is also obvious in different mobility cases, despite the variations between different codecs observed in the obstructed case contrary to the free-space case. In addition, the distributions of MOS samples for the set of used codecs were produced. Although G.711 seems to perform worse an average, it can reach higher values of MOS which seems impossible for G.723.1 and G.729a. A time-based evaluation verifies these results, as higher performance of G.711 is alleviated by more frequent and deeper spikes compared to other codecs.

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