A MOS-based Routing Approach for Wireless Mesh Networks

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Abstract—In this paper we propose a routing approach aimed at enhancing the quality of Voice-over-IP transmissions in multi-path Wireless Mesh Networks. The proposed approach executes a path switching based on the estimation of the Mean Opinion Score (MOS) for each available path of the mesh network. Performance results conducted through simulations show that the proposed approach, when compared to a random choice of the available paths, is highly effective in improving the performance of the VoIP calls in both static and dynamic scenarios.

I. INTRODUCTION

In the last couple of years there has been an increasing interest in the Wireless Mesh Networks (WMNs) and in particular in the various services offered by such type of networks [1]. WMNs allow to create a reliable wireless broadband service access in a way that needs minimal up-front investments. The wireless backbone infrastructure which characterizes the WMNs allows to convey data packets and consequently services to a multitude of people, for example in under-resourced communities, providing in this way new quality-of-life opportunities and new technological capabilities in education, healthcare and employment [2].

Among the services offered by the WMNs, one of the most significant is the Voice-over-IP (VoIP). Carrying voice over an IP network has gained a significant importance in the last years thanks to the development of cell phones with wifi capabilities, and soft-phones over PDAs. The advantages of VoIP are various. First of all, the VoIP provides the users a low cost phone service which is based on a pre-existing data infrastructure without the need of creating a new communication network. Secondly, VoIP gives the users the potential to connect every time a wireless LAN connection is present, for example abroad, without the high cost of the cellular roaming service. Furthermore, VoIP allows to integrate the voice call with other services available over the Internet, including video conversation, audio conferencing, message or data file exchange during the conversation.

The characteristics of the VoIP service require a wide area wireless coverage which has been recently obtained through the IEEE 802.11-based wireless mesh networks. However, supporting real-time applications such as VoIP over WMNs is a challenging task. In fact, due to the changing wireless channel conditions and interference, delay and jitter can vary over time along the multi-hop path between a source and a destination node. Such variations can have a severe impact on the quality of the voice call.

Since WMNs share common features with ad hoc networks, the classical protocols developed for ad hoc networks has been applied also to WMNs, but they suffer of scalability issues [1]. Specifically, classical routing protocols used in ad hoc networks are not suitable for WMNs due to some peculiar characteristics of the mesh networks. Primarily, one of the objectives of WMNs is to share the network link among many users. When a section of a WMN suffers congestion, the new traffic flows should be routed through another link. Instead, almost all the classical routing protocols for ad hoc networks use minimum hop-count as a metric to select the routing path without taking into account the load balancing. To this purpose, a significant interest has been related to the area of switching among the multiple paths available in the WMN. Some strategies use an overlay network [3], some others use a routing protocol supporting multiple paths [4].

In this paper, we investigate the performance of the voice communications over a wireless mesh networks and we propose a novel strategy in which the path is chosen according to the MOS score estimated on each path of the mesh network through a probe mechanism. A similar approach has been mentioned in [5], together with some others improvements on a 802.11-based mesh networks in order to efficiently support the VoIP calls. However, a MOS-based routing approach, if not properly designed, can cause severe traffic oscillations among the links involved in the communication. The main contribution of this work is that we take into account, in the calculation of the MOS score, some factors which increase the accuracy of the MOS and reduce fluctuations among the links. Also, we evaluate the proposed routing protocol in comparison with a random choice of the paths, and we discuss its behavior when the traffic conditions in the mesh network change.

II. REFERENCE SCENARIO AND METRICS

This section describes the mesh network we considered as reference scenario, the protocols, and the metrics we used in the following of the paper.
A. Reference Scenario

We consider a mesh network characterized by $N$ Wireless Access Points (WAPs) connected together to form a wireless backbone as illustrated in Fig. 1. The WAPs can be 802.11-based access points having two radios working in orthogonal channels in order to both connect to the other WAPs of the network and allow the WAP to work as a hot spot providing services to the Wireless Mobile nodes (WMs). At the edges of the mesh network we consider two access routers. With reference to the layout in Fig. 1, we simply refer to them as LWAP (left side) and RWAP (right side). The mesh network is connected to the Internet through RWAP by a wired link. Moreover, we consider $k$ disjoint paths each of them having $N/k$ WAPs and we assume that each data packet belonging to a connection between two WMs, can follow a different path to travel from one point to another point of the network.

B. VoIP

A VoIP system requires the following operations to be performed: voice digitalization, which is the conversion of voice from an analog to a digital signal; noise cancellation, which is the procedure for separating the voice signal from environmental noise; voice compression, which reduces the amount of bandwidth necessary to transmit digitized voice. Voice compression and noise cancellation are usually achieved through the use of codecs such as G.723, G.728, G.729 or G.711. The main difference between the codecs lies in the type and amount of bandwidth necessary to transmit digitized voice.

C. Metrics

Among the several parameters used to measure the quality of the voice call, the most common is the MOS. The abbreviation MOS (Mean Opinion Score) is defined by ITU-T Rec. P.10/G.100 as “The mean of opinion scores, i.e., of the values on a predefined scale that subjects assign to their opinion of the performance of the telephone transmission system used either for conversation or for listening to spoken material”.

Apart from subjective opinion, the ITU-T Recommendation G.107 [6] defines an objective model, known as E-Model, that allows to estimate the perceived quality of VoIP communications. In particular, following the E-Model, the MOS for listening-only applications (MOS-LQE, where “LQ” refers to Listening Quality and “E” refers to Estimated) can be calculated through a single scalar, called “R factor,” which takes into account both signal-to-noise ratio and possible impairments (e.g., delay and loss).

$$\text{MOS-LQE} = \begin{cases} 1 & \text{for } R \leq 0 \\ 1 + 0.035R + +7R(R-60)(100-R)10^{-6} & \text{for } 0 < R < 100 \\ 4.5 & \text{for } R \geq 100 \end{cases}$$

The R-factor is composed as the sum of five terms

$$R = R_o - I_s - I_d - I_{e-eff} + A$$

where $R_o$ represents the basic signal-to-noise-ratio (taking into account the room or circuit noise sources); $I_s$ is an impairment factor associated with impairments which may occur more or less simultaneously with the voice transmission; $I_d$ is an impairment factor associated with the mouth-to-ear delay of the path; $I_{e-eff}$ is an impairment factor associated with the loss caused by low bit-rate codecs and packet-loss of random distribution; $A$ is an Advantage Factor used to take into account the advantages related to a specific system (i.e. the mobility of a cellular network). As proposed in [7], by neglecting some terms to take into account only the impairments due to the network, the R factor can be evaluated as follows:

$$R = 94.2 - I_d - I_{e-eff}$$

III. PROPOSED MECHANISM

The proposed mechanism is implemented at the application layer and, acting in a cross-layer fashion, modifies the routing table of the access routers (e.g. LWAP and RWAP in Fig. 1) so that it is possible to select the path having the best quality. Specifically, the mechanism is implemented through two modules: the probe module devoted to the collection of the parameters needed to estimate the MOS; and the MOS refiner module dedicated to estimate the MOS.

![Fig. 1: Mesh topology.](image-url)
A. Probe module

The probe module is implemented in the access routers and it is devoted to collect parameters needed to estimate the MOS value for the different paths of the mesh network.

The mechanism takes into account different parameters, such as delay, jitter and packet loss, which characterize the quality of the voice signal, as already discussed in Section II-C. Specifically, the module emits a burst of packets, having the same characteristics of the VoIP traffic (same packet size, same inter-packet time of the specific codec) with a periodicity $T$, during a time interval $t$, which is an integer multiple of the inter-packet time, $\tau$, as illustrated in Fig. 2. Within the time interval between the emission of two bursts of packets, the mechanism performs an update of the routing table. To this purpose, we have considered a new field inside the routing tables, so that, for any possible route, it is possible to store the value of the MOS-LQE, as described in Section III-B. Concerning the scenario shown in Fig. 1, the probe module is implemented inside LWAP and RWAP, in order to collect parameters needed to estimate the MOS in the $k$ paths which constitute the $k$ disjoint links between the access routers. Specifically, the burst of packets sent from node LWAP are received by the node RWAP, which measures the basic parameters and then estimate the MOS (as in eq. (1)) related to each path $i$, in the direction $L-R$. The MOS estimated by RWAP will be sent, using the piggy-backing, inside the probe traffic towards LWAP. Once the burst of packet has been received, LWAP will update its own routing tables, as discussed below. Since the mechanism is implemented symmetrically, the burst sent from the node RWAP allows LWAP to estimate the MOS related to the different paths in the opposite direction $R-L$. These values, will be sent, in the same way, to RWAP which will update its routing tables accordingly.

B. MOS refiner module

The value of MOS for each path $i$, $MOS[i][n]$, which should be stored in the routing tables, is obtained considering the estimated MOS value received in piggy-backing inside the last packet of the $n$-th burst of probe traffic, $MOS[i][n]$, and multiply it for the following ratio ($C1$): number of packets received in the latest burst (recv_probe_pkts-i) over the number of packets sent for each burst (n_burst_pkts).

$$MOS[i][n] = MOS[i][n] \cdot \frac{\text{recv_probe_pkts-i}}{\text{n_burst_pkts}}$$  

This calculation allows the access router to take into account the traffic condition of the link in the direction of the packets received. This is particularly useful when there is congestion in the direction of the packets received (i.e. fewer packets are received than expected) because it permits to decrease the value of the estimated MOS. Then, the $MOS[i][n]$ value is filtered using a first order IIR low-pass filter. The filter is used to adjust the value of the estimated MOS to avoid rapid fluctuations due to instantaneous changes in the traffic conditions. Specifically, the filter used in the proposed mechanism is:

$$\bar{MOS}_i[n+1] = \alpha \bar{MOS}_i[n] + (1-\alpha)MOS_i[n]$$  

The variable $\alpha$ can be tuned to obtain a faster update of the refined MOS value. As an example, once the value of the burst $T$ has been fixed, the variable $\alpha$ can be initialized in order to have a rise time, $t_r$, from $20\%$ to $80\%$, in the following way: $t_r = -1.4\frac{T}{\alpha ln 2}$. Let us assume there is some data traffic flowing from RWAP to LWAP which can take $k$ possible disjoint paths. Let $A_1, A_2, ..., A_k$, be the addresses of the next-hops stored in the routing table of LWAP. The proposed mechanism allows to store in the routing table the MOS values for the different paths: $MOS_1, MOS_2, ..., MOS_k$. LWAP will select the next-hop node to be used as forwarder in the following way: $A_1 : MOS = \max_{j=1}^{k} MOS_j$, i.e., the address related to the maximum refined MOS.

C. Pseudo code

The implemented mechanism can be described using the following pseudo code:

For each path $i$:
- Expires_Timer T1-i:
  - C1 = recv_probe_pkts-i / n_burst_pkts
  - MOS-R-i = PB-E-MOS-i * C1
  - AR-Filter(Mean-MOS-R-i, MOS-R-i)
  - Update_Routing_Table(i, Mean-MOS-R-i)
  - sent_probe_pkts-i = 0
  - recv_probe_pkts-i = 0
  - Reset_Mean_Delay
  - Reset_Mean_Packet_Loss_Ratio
  - Start_Timer T2-i
- Start_Timer T1-i
- Expires_Timer T2-i:
  - Initialize_Probe_Packet
  - Send_Probe_Packet
  - incr sent_probe_pkts-i
  - if sent_probe_pkts-i < n_burst_pkts { Start_Timer T2-i }
- Received_Probe_Packet:
  - Update_Mean_Delay
  - Update_Mean_Packet_Loss_Ratio
  - Evaluate E-MOS-i
  - Update PB-E-MOS-i
  - incr recv_probe_pkts-i

In the above pseudo code, T1-i and T2-i are two timers for each path. The timers T1-i are initialized to expire after a time interval equal to $T$, the timers T2-i are initialized to expire after an interval equal to the inter-packet time, $\tau$. 

![Fig. 2: Probe module timing.](image-url)
When an access router receives a probe packet from a path \(i\), it calculates the time spent by the packet to cross the network, using the timestamp inside the header of the RTP protocol, and then it updates the average delay, \(\text{Update\_Mean\_Delay}\). Moreover, using the sequence number of the received packet, it is possible to determine the number of lost packets and then calculate the average number of the received packet, it is possible to determine the refined MOS value calculated for the paths, and all the support variables will be re-initialized.

The number of WMs connected to each W AP is different for each path. Specifically, we suppose that it increases linearly: \(\text{recv\_probe\_pkts}\_i\) according to eq. (6), by taking into account the number of packets received during the burst, \(\text{recv\_probe\_pkts}\_i\), and the number of packets sent in a burst, \(n\_burst\_pkts\). The value of MOS estimated for the path \(i\) is updated according to eq. (6), by taking into account the number of packets received during the burst, \(\text{recv\_probe\_pkts}\_i\), and the number of packets sent in a burst, \(n\_burst\_pkts\). The value of MOS estimated for the path will be used to update, by using the IIR filter, the average value of the MOS for that path, \(\text{Mean-MOS}\_R\_i\), according to eq. (7). Finally, the routing table of the node will be updated according to the refined MOS value calculated for the paths, and all the support variables will be re-initialized.

IV. PERFORMANCE RESULTS

Here we show some results obtained for the proposed mechanism when used in a static and dynamic scenario.

A. Static Scenario

Fig. 3 shows the WMN topology we used to calculate the performance of the proposed mechanism in a static scenario (i.e. when the traffic conditions in the different paths are constant during the simulation). The WMN is composed by 9 WAPs placed along three rows and three columns, and by two other access points used as access routers (LW AP and RW AP). Each WAP is located inside a grid with a step length equal to 100m. Only the WAPs in the same row operate in the same wireless channel, so that it is possible to identify three disjoint paths, referred as: path 1, path 2 and path 3. Accordingly, the wireless backbone consists of three non-interfering channels: ChB1, ChB2, ChB3, for path 1, path 2, and path 3, respectively. Each WAP of the WMN operates both in ad hoc mode to connect to the wireless backbone, and in infrastructure mode to connect to the wireless mobile nodes (WMs). Accordingly, each WAP has two physical interfaces and two MAC layers which allow to simultaneously connect to the wireless backbone and to the WM [1]. The channel used in the infrastructure mode, ChA, is the same for all the WAPs. The number of WMs connected to each WAP is different for each path. Specifically, we suppose that it increases linearly: \(\text{in the path } 1\), is equal to \(1\); in the path \(2\), is equal to \(4\); in the path \(3\), is equal to \(7\).

Nodes LWAP and RWAP have four different wireless interfaces which allow to join the channel ChA and the three different channels ChB. Moreover, RWAP has a wired interface for connecting to the wired network. Each WM connected to the WAP communicates with some Fixed Hosts (FHs) located in the wired network. VoIP communication is performed by generating and receiving a Constant Bit Rate (CBR) traffic which flows through RWAP. The characteristics of the traffic are: inter-packet time (\(\tau\)) equal to 0.02s; packet size equal to 180 bytes (e.g. using a G.711 codec); throughput equal to 72kbps. Moreover, we assume that: CBR traffic is continuous; the sources start in a random manner during a time interval of 2s; the duration of the simulation is equal to 180s, which corresponds to the average duration of a phone call. In our simulations, this data traffic constitutes the so-called background traffic, while the results have been obtained collecting the metrics related to the WM s connected to LWAP and RWAP. These WM s generate and receive a CBR traffic towards the wired network having the same characteristics seen above, and their number ranges from 1 to 15.

When the proposed mechanism is not working, each packet traveling from LWAP to RWAP is routed through one of the three available paths chosen in a random manner. Otherwise packets are routed towards the path having the highest estimated MOS. The choice of the next-hop node is performed in a static manner using the routing table presents in each node. The routing table is updated using the mechanism described in the previous section, where the probe traffic has the following characteristics: \(T = 1s\) and \(t = 0.2s\) (corresponding to 10 probe packets sent in a burst, \(n\_burst\_pkts=10\)). Concerning the filter, the parameter \(\alpha\) has been chosen equal to 0.87055 (raise time \(t_r\approx10s\)). The results have been obtained using the simulator ns-2 [9] with the miracle extension [10].

B. Static Scenario Results

Fig. 4 shows the average Throughput (Th), Packet Error Rate (PER), Forward Trip Time (FTT), and MOS, related to the WM s connected to LWAP when their number changes. In each figure, the solid line represents the values obtained when the proposed mechanism is used, and the dashed line when the mechanism is disabled.
Concerning the MOS values calculated for the paths 1 of WMs, and consequently exhibits the highest background. The steady-state is reached, the MOS calculated in the path 1 of WMs attached to LW AP equals to 7. As expected, when attached to LW AP and for the three possible paths, here the proposed mechanism is used, averaged over the WMs account the effect of both delay and packet error rate. The results confirm the effectiveness of a routing based on the MOS and PER (Fig. 4b) and FTT (Fig. 4c) increase. However, using the proposed mechanism, PER keeps lower than the value obtained for the random choice of the links, whereas FTT achieves a value higher than the value obtained when the mechanism is disabled. This is due to the fact that, using our mechanism, only a path is selected in the short term (i.e. the path having the highest MOS), consequently it happens that, when the number of WMs increases, a high number of packets remains in the queue of that path, so increasing the average delay. Moreover, it should be noted that the FTT is based on the number of received packets. So, when the packet error rate is high (as especially happens when the mechanism is disabled, see Fig. 4b) the value of FTT can be underestimated because it is based on the few packets which reach the destination.

The value of MOS, shown in Fig. 4d, reflects the previous trends. In particular, when the proposed mechanism is used, the MOS is always higher (almost 4 times) as compared to when the mechanism is not used, with the exception of the case the number of sources is greater than 11. This is a consequence of the fact that above 11 sources the FTT start to increase rapidly and consequently the MOS degrades. The results confirm the effectiveness of a routing based on the MOS parameter, because the choice of the path takes into account the effect of both delay and packet error rate.

The number of WMs, and consequently the MOS calculated for the paths 1 and 2, are influenced by the traffic generated by the WMs attached to the LWAPs. Initially, the MOS calculated for the path 1 is the highest (this path is characterized by the lowest number of WMs), and consequently the traffic generated is routed along this path. Afterwards, the MOS in path 1 degrades (due to the traffic flowing in this link) and at around t=50s (see Fig. 5) it reaches a value lower than the value obtained in path 2, consequently LWAP selects path 2 to route the packets. Around t=60s, MOS in path 2 degrades rapidly (note that this path is characterized by a background traffic which is 4 times higher than path 1), and the traffic is routed again towards path 1. As a consequence, MOS in path 2 starts to rise with a velocity which depends on the coefficients chosen for the filter, and MOS in path 1 decreases till a minimum value at time t=125s. At this time the routing mechanism performs again a path switching. This cyclic behavior is repeated again with a periodicity which depends on the IIR filter parameters and the traffic conditions.

C. Dynamic Scenario

In order to investigate how the proposed mechanism reacts to changes in the network conditions, we have evaluated its performance in a dynamic scenario, where specifically the background traffic, which is generated by the WMs attached to the WAPs, varies over the time. The network topology and the time range of activities of the WMs are illustrated in Fig. 6, all the other parameters are the same as in Section IV-A.

We have assumed: 7 WMs attached to each WAP of the
network; 15 WMs attached to LWAP; the duration of the simulation equal to 240s. Moreover, we have considered the following background traffic profile: the WMs belonging to the path 1 generate and receive data traffic during the time interval $[60, 180]$s; the WMs belonging to the path 2 generate and receive data traffic during the time intervals $[0, 60]$s and $[120, 240]$s; the WMs belonging to the path 3 generate and receive data traffic during the time intervals $[0, 120]$s and $[180, 240]$s.

D. Dynamic Scenario Results

Fig. 7 shows the temporal evolution of the throughpath and the MOS estimated by the probe mechanism, averaged over the 15 sources connected to the LWAP. It is possible to observe that, in correspondence of the changes in the background traffic, there is a degradation of both throughput and MOS. This degradation lasts for 10s after the time instant when the traffic condition changes. Moreover, its duration is related to the filter parameters chosen. Once the proposed mechanism selects the best available path, MOS and throughput return to their previous values. We have considered the worst condition, that is when the traffic in the paths changes from zero to a full load within a very short time interval equal to 1s.

Looking at Fig. 7b, which shows the estimated MOS for the three paths, it is possible to observe that, as expected, the data traffic is routed towards the path where the MOS is higher. Once the background traffic is activated along the path, its MOS value goes down quickly (with a velocity higher than the rise time) because the new traffic conditions cause an increase in the packet loss probability and, consequently, a decrease of the MOS calculated using eq. (6 and 7). Accordingly, the mechanism will react by redirecting the traffic to the path with the best MOS value.

V. CONCLUSIONS

In this paper we have proposed a routing approach for VoIP traffic, based on the evaluation of the MOS in multi-path wireless mesh networks. First, we have described how the MOS, for the available paths, can be evaluated and properly tuned. Then, we have described how the path can be selected according to the MOS value. Finally, we have compared its performance with a random choice of the paths. Results obtained show that the proposed approach increases the quality of the VoIP in both static and dynamic scenarios.

REFERENCES