Simultaneous VoIP Calls Capacity Over an 802.11 Ad Hoc Network

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Abstract

Voice over Internet Protocol (VoIP) over a wireless local area network (WLAN) is already an important Internet application. The data rate required for each VoIP stream depends on the used codec and the TCP/IP protocol overhead that typically add 98 bytes in the codec payload. As the G.726 codec has 80-byte payload (32 kb/s), the overhead represents 55% of the total packet size (178 bytes). This increases the raw data rate to 71.2 kb/s and limits the number of simultaneous VoIP calls. On the other hand, if the codec employed is G.729 the payload is much lower (20 bytes) and the raw data rate decreases to 47.2 kb/s, but the VoIP delay increases substantially due to the packetization time. There is a relationship between throughput and a target delay to investigate the maximum number of simultaneous VoIP calls in an 802.11b WLAN network in ad hoc mode operating with multihops. This paper analyses the simultaneous VoIP calls capacity to ad hoc network operating at 11 Mb/s in up to four hops.

Keywords: 802.11, ad hoc, throughput, VoIP, WLAN.

1. Introduction

In contrast to the big progress of wireless systems, many countries in all over the world still have a lot of people that do not have access to any kind of telecommunication service. Typically these people live in small communities or rural areas, where the deployment costs of telecommunications networks are economically unviable, which is one of the reasons for the current scenario.

As wireless local area network can be ad hoc, which is characterized for operating without central infrastructure and each node communicates directly to each other, the deployment of this network is cheaper than traditional telecommunication solutions.

A system based on ad hoc wireless network can be an alternative to provide telecommunications services to these disadvantaged individuals and communities.

On the other hand, in an ad hoc network each node implements distributed medium access control (MAC) mechanisms and deal with exposed and hidden terminal problems, adding considerable complexity to nodes, especially in multihop networks, where they also act as routers. Besides, ad hoc networks must cope with other wireless medium problems, such as low transmission rate, high bit error rate (BER), and significant variations in physical medium conditions.

This complexity added to the throughput decrease due to the multihops, make transmission of real-time traffic like VoIP a great challenge.

2. Scenario description

The tests were carried out in an ad hoc network installed inside of a company building. The ad hoc network nodes consist of fixed PCs equipped with 802.11b wireless interfaces. The operational system used in the nodes was Linux Red Hat 9.0 [1] running the AODV routing protocol [2].

Figure 1 shows the ad hoc nodes disposition.

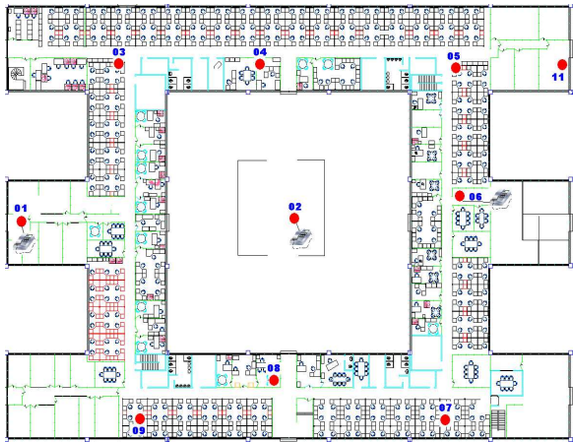

Figure 1. Ad hoc nodes disposition.

The TABLE I shows the ad hoc nodes configurations.

TABLE I. Ad hoc nodes configurations.

Desktop	Processor	Memory	WLAN Card	Kernel Version
1	Pentium 4 1.5 GHz	256 MB	PCI Cisco Aironet 350	2.4.26
2	Pentium 4 1.5 GHz	512 MB	USB ASUS	2.4.20-8
3	Pentium 2 400 MHz	64 MB	PCI Cisco Aironet 350	2.4.26
4	Celeron 400 MHz	96 MB	USB ASUS	2.4.20-8
5	Pentium 2 400 MHz	64 MB	PCI Cisco Aironet 350	2.4.26
6	Pentium 4 1.5 GHz	512 MB	PCI Cisco Aironet 350	2.4.26
7	Pentium 3 650 MHz	128 MB	PCI Cisco Aironet 350	2.4.26
8	Pentium 3 450 MHz	64 MB	USB Atmel	2.4.20-8
9	Pentium 2 400 MHz	128 MB	PCI Cisco Aironet 350	2.4.26

3. Simultaneous VoIP Calls test

The range of private IP address was 10.5.0.x. The distance between nodes was in order to guarantee at least raw data rate of 11 Mb/s. This was an important point to be considered because the simultaneous VoIP calls capacity depends on that data rate.

The following premises have been adopted: 1) The maximum VoIP capacity is the number of maximum ad hoc node hops and simultaneous VoIP calls at 11 Mb/s limited by the minimum target MOS (Mean Opinion Score) of 3.20 that will be analyzed based on system performance parameters as delay, jitter and packet loss and characteristics of three types of codecs. 2) One hop is the communication between a pair of ad hoc nodes. 3) RTS/CTS, fragmentation and silence suppression mechanisms were unable.

MOS is a subjective score of voice quality as perceived by people listening to speech over a communication system.

A MOS of 5 is excellent; a MOS of 1 is unacceptably bad. The TABLE II from [4] summarizes the relationship between the MOS and user satisfaction.

TABLE II. MOS and user satisfaction.

Mean Opinion Score (lower limit)	User Satisfaction
4.34	Very satisfied
4.03	Satisfied
3.60	Some users dissatisfied
3.10	Many users dissatisfied
2.58	Nearly all users dissatisfied

In simultaneous VoIP-call tests were considered three codecs: G.711, G.726 and G.729. Some characteristics of these three codecs are shown in TABLE III.

TABLE III. Codecs characteristics.

Standard	Payload (bytes)	Datagram Size (ms)	Data Rate (kb/s)	Packetization Delay (ms)
ITU-T G.711	160	20	64	1.0
ITU-T G.726	80	20	32	1.25
ITU-T G.729	20	20	8	25

It is worth noting that: 1) RTP/UDP/IP/MAC/PHY protocols overhead consists of 98 bytes [3] and this represents more than the G.726 codec payload value and much more than the G.729 codec payload value. 2) The packetization delay refers to the delay that the codecs introduce as they convert a signal from analog to digital. This delay is included in the MOS estimate.

3.1. Simultaneous VoIP Calls capacity

The simultaneous VoIP calls capacity was tested using appropriated software to simulate end-to-end simultaneous VoIP calls between ad hoc node pairs inside the building increasing the number of hops until reaching close to the minimum target MOS. Treating each ad hoc node pair as a separate VoIP call, the

software gives an indication of the relative quality of each call made during a test on ad hoc network. It uses a modified version of the ITU G.107 [4] standard E-Model equation to calculate a MOS estimate for each ad hoc node pair.

The E-Model, developed by the European Telecommunications Standards Institute (ETSI), has become ITU standard G.107. This algorithm is meant to evaluate the quality of a transmission by factoring in the "mouth-to-ear" characteristics of a speech path. It calculates an R-value, which correlates directly with the MOS estimate.

It was considered 95% confidence interval of the measured time for each timing record. The confidence interval is a statistical measurement for the reliability of the calculated average.

3.2. Test with G.711 μ codec

Part of the software used in these tests does not run in Linux, only in Windows. Due to this reason, it was used a fixed laptop as the first ad hoc node of the network with 10.5.0.100 IP address.

3.2.1 The first test

The first test was carried out considering the G.711 μ codec, seven simultaneous VoIP calls in only one hop from/to 10.5.0.100 to/from 10.5.0.1. The first test setup is shown in Figure 2.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.711u		**344**				
Pair 1	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 2	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 3	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 4	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 5	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 6	Finished	49	10.5.0.100	10.5.0.1	RTP	G.711u
Pair 7	Finished	50	10.5.0.100	10.5.0.1	RTP	G.711u

Figure 2. The first test setup.

The MOS results are shown in Figure 3.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.711u		**344**	**4,36**	**3,81**	**4,38**	**91,24**
Pair 1	Finished	49	4,36	3,81	4,38	91,23
Pair 2	Finished	49	4,36	3,81	4,38	91,23
Pair 3	Finished	49	4,36	3,81	4,38	91,24
Pair 4	Finished	49	4,36	3,81	4,38	91,24
Pair 5	Finished	49	4,36	3,81	4,38	91,23
Pair 6	Finished	49	4,36	3,81	4,38	91,23
Pair 7	Finished	50	4,36	3,81	4,38	91,25

Figure 3. First test MOS results.

The average MOS of the seven calls through the same pair was 4.36 and is bigger than the minimum target.

3.2.2 The second test

The second test was carried out considering seven simultaneous VoIP calls in two hops from/to node 1 (10.5.0.1) to/from node 5 (10.5.0.5) passing by node 3. The second test setup is shown in Figure 4.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.711u		**347**				
Pair 1	Finished	49	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 2	Finished	50	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 3	Finished	50	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 4	Finished	50	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 5	Finished	49	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 6	Finished	50	10.5.0.1	10.5.0.5	RTP	G.711u
Pair 7	Finished	49	10.5.0.1	10.5.0.5	RTP	G.711u

Figure 4. The second test setup.

The MOS results are shown in Figure 5.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.711u		**347**	**4,30**	**2,50**	**4,38**	**89,58**
Pair 1	Finished	49	4,27	2,50	4,38	88,83
Pair 2	Finished	50	4,29	2,77	4,38	89,29
Pair 3	Finished	50	4,32	3,75	4,38	90,00
Pair 4	Finished	50	4,32	3,17	4,38	90,05
Pair 5	Finished	49	4,31	3,17	4,38	89,65
Pair 6	Finished	50	4,31	3,17	4,38	89,64
Pair 7	Finished	49	4,30	2,76	4,38	89,60

Figure 5. Second test MOS results.

The average MOS of the seven simultaneous calls with two hops was 4.30. This result is lower than first result but is bigger than the minimum target.

3.2.3 The third test

The third test was carried out considering seven simultaneous VoIP calls in three hops from/to laptop (10.5.0.100) to/from node 5 (10.5.0.5) passing by nodes 1 and 3. The third test setup is shown in Figure 6.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.711u		**336**				
Pair 1	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 2	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 3	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 4	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 5	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 6	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u
Pair 7	Finished	48	10.5.0.100	10.5.0.5	RTP	G.711u

Figure 6. The third test setup.

The MOS results are shown in Figure 7.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.711u		**336**	**3,21**	**1,00**	**4,38**	**60,51**
Pair 1	Finished	48	3,18	1,00	4,38	59,89
Pair 2	Finished	48	3,21	1,00	4,38	60,38
Pair 3	Finished	48	3,20	1,00	4,38	60,72
Pair 4	Finished	48	3,21	1,00	4,38	60,53
Pair 5	Finished	48	3,17	1,00	4,38	59,72
Pair 6	Finished	48	3,29	1,00	4,38	62,53
Pair 7	Finished	48	3,18	1,00	4,38	59,81

Figure 7. Third test MOS results.

The average MOS of the seven simultaneous VoIP calls with three hops was 3.21. This result is lower than second result but is bigger than the minimum target.

3.2.4 The fourth test

The fourth test was carried out considering seven simultaneous VoIP calls in four hops from/to laptop (10.5.0.100) to/from node 6 (10.5.0.6) passing by nodes 1, 3 and 5. The fourth test setup is shown in Figure 8.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.711u		**282**				
Pair 1	Finished	40	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 2	Finished	40	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 3	Finished	40	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 4	Finished	41	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 5	Finished	40	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 6	Finished	40	10.5.0.100	10.5.0.6	RTP	G.711u
Pair 7	Finished	41	10.5.0.100	10.5.0.6	RTP	G.711u

Figure 8. Fourth test setup.

The MOS results are shown in are shown in Figure 9.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.711u		**282**	**1,76**	**1,00**	**3,88**	**24,36**
Pair 1	Finished	40	1,76	1,00	3,86	24,48
Pair 2	Finished	40	1,75	1,00	3,84	24,26
Pair 3	Finished	40	1,74	1,00	3,87	23,99
Pair 4	Finished	41	1,76	1,00	3,69	24,19
Pair 5	Finished	40	1,75	1,00	3,85	24,13
Pair 6	Finished	40	1,75	1,00	3,85	24,13
Pair 7	Finished	41	1,80	1,00	3,88	25,37

Figure 9. MOS results with four hops.

The average MOS of the seven simultaneous VoIP calls with four hops was 1.76. This result is lower than the minimum target.

3.3. Test with G.726 codec

This item shows the results of simultaneous VoIP calls capacity with G.726 codec.

3.3.1 The first test

The first test was carried out considering the G.726 codec, seven simultaneous VoIP calls in only one hop from/to 10.5.0.100 to/from 10.5.0.1. The first test setup is shown in Figure 10.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.726		**344**				
Pair 1	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726
Pair 2	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726
Pair 3	Finished	50	10.5.0.100	10.5.0.1	RTP	G.726
Pair 4	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726
Pair 5	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726
Pair 6	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726
Pair 7	Finished	49	10.5.0.100	10.5.0.1	RTP	G.726

Figure 10. The first test setup.

The MOS results are shown in Figure 11.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.726		**344**	**4,11**	**3,68**	**4,20**	**82,61**
Pair 1	Finished	49	4,11	3,68	4,20	82,57
Pair 2	Finished	49	4,12	3,68	4,20	82,83
Pair 3	Finished	50	4,10	3,68	4,20	82,36
Pair 4	Finished	49	4,11	3,68	4,20	82,57
Pair 5	Finished	49	4,10	3,68	4,20	82,31
Pair 6	Finished	49	4,11	3,69	4,20	82,57
Pair 7	Finished	49	4,13	3,69	4,20	83,09

Figure 11. First test MOS results.

The average MOS of the seven simultaneous calls through the same pair was 4.11 and is bigger than the minimum target.

3.3.2 The second test

The second test was carried out considering seven simultaneous VoIP calls in two hops from/to node 1 (10.5.0.1) to/from node 5 (10.5.0.5) passing by node 3. The second test setup is shown in Figure 12.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.726		**344**				
Pair 1	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 2	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 3	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 4	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 5	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 6	Finished	49	10.5.0.1	10.5.0.5	RTP	G.726
Pair 7	Finished	50	10.5.0.1	10.5.0.5	RTP	G.726

Figure 12. The second test setup.

The MOS results are shown in Figure 13.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.726		**344**	**4,18**	**3,68**	**4,20**	**84,54**
Pair 1	Finished	49	4,18	3,68	4,19	84,48
Pair 2	Finished	49	4,18	3,68	4,19	84,54
Pair 3	Finished	49	4,18	3,68	4,19	84,45
Pair 4	Finished	49	4,19	3,69	4,20	84,65
Pair 5	Finished	49	4,18	3,69	4,20	84,60
Pair 6	Finished	49	4,18	3,69	4,19	84,56
Pair 7	Finished	50	4,18	3,68	4,19	84,52

Figure 13. Second test MOS results.

The average MOS of the seven simultaneous VoIP calls with two hops was 4.18. This result is bigger than first result and the minimum target. The difference between the first and the second average MOS is due to the canal condition at the moment of the tests.

3.3.3 The third test

The third test was carried out considering seven simultaneous VoIP calls in three hops from/to laptop (10.5.0.100) to/from node 5 (10.5.0.5) passing by nodes 1 and 3. The third test setup is shown in Figure 14.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.726		**343**				
Pair 1	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 2	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 3	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 4	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 5	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 6	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726
Pair 7	Finished	49	10.5.0.100	10.5.0.5	RTP	G.726

Figure 14. The third test setup.

The MOS results are shown in Figure 15.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.726		**343**	**3,25**	**1,00**	**4,20**	**61,13**
Pair 1	Finished	49	3,21	1,00	4,20	59,66
Pair 2	Finished	49	3,22	1,00	4,20	61,17
Pair 3	Finished	49	3,25	1,00	4,20	61,04
Pair 4	Finished	49	3,23	1,00	4,20	60,70
Pair 5	Finished	49	3,24	1,00	4,20	60,22
Pair 6	Finished	49	3,28	1,00	4,20	62,39
Pair 7	Finished	49	3,31	1,00	4,20	62,72

Figure 15. Third test MOS results.

The average MOS of the seven simultaneous VoIP calls with three hops was 3.25. This result is lower than second result but is bigger than the minimum target.

3.3.4 The fourth test

The fourth test was carried out considering seven simultaneous VoIP calls in four hops from/to laptop (10.5.0.1) to/from node 7 (10.5.0.7) passing by nodes 3, 5 and 6. The fourth test setup is shown in Figure 16.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.726		**350**				
Pair 1	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 2	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 3	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 4	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 5	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 6	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726
Pair 7	Finished	50	10.5.0.1	10.5.0.7	RTP	G.726

Figure 16. Fourth test setup.

The MOS results are shown in are shown in Figure 17.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.726		**350**	**3,14**	**1,13**	**4,17**	**61,29**
Pair 1	Finished	50	3,16	1,16	4,17	61,70
Pair 2	Finished	50	3,14	1,16	4,17	61,42
Pair 3	Finished	50	3,12	1,13	4,17	61,00
Pair 4	Finished	50	3,11	1,15	4,17	60,69
Pair 5	Finished	50	3,16	1,15	4,17	61,74
Pair 6	Finished	50	3,13	1,14	4,17	61,21
Pair 7	Finished	50	3,14	1,14	4,17	61,29

Figure 17. MOS results with four hops.

The average MOS of the seven simultaneous VoIP calls with four hops was 3.14. This result is lower than the minimum target.

3.4. Test with G.729 codec

This item shows the results of simultaneous VoIP calls capacity with G.729 codec.

3.4.1 The first test

The first test was carried out considering the G.729 codec, seven simultaneous VoIP calls in only one hop from/to 10.5.0.100 to/from 10.5.0.1. The first test setup is shown in Figure 18.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.729		**344**				
Pair 1	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729
Pair 2	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729
Pair 3	Finished	50	10.5.0.100	10.5.0.1	RTP	G.729
Pair 4	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729
Pair 5	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729
Pair 6	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729
Pair 7	Finished	49	10.5.0.100	10.5.0.1	RTP	G.729

Figure 18. The first test setup.

The MOS results are shown in Figure 19.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.729		**344**	**4,01**	**3,68**	**4,04**	**79,54**
Pair 1	Finished	49	4,01	3,68	4,04	79,54
Pair 2	Finished	49	4,01	3,68	4,04	79,54
Pair 3	Finished	50	4,01	3,68	4,04	79,56
Pair 4	Finished	49	4,01	3,68	4,04	79,54
Pair 5	Finished	49	4,01	3,68	4,04	79,54
Pair 6	Finished	49	4,01	3,68	4,04	79,54
Pair 7	Finished	49	4,01	3,68	4,04	79,54

Figure 19. First test MOS results.

The average MOS of the seven simultaneous VoIP calls through the same pair was 4.01 and is bigger than the minimum target.

3.4.2 The second test

The second test was carried out considering seven simultaneous VoIP calls in two hops from/to node 1 (10.5.0.1) to/from node 5 (10.5.0.5) passing by node 3. The second test setup is shown in Figure 20.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.729		**348**				
Pair 1	Finished	49	10.5.0.1	10.5.0.5	RTP	G.729
Pair 2	Finished	50	10.5.0.1	10.5.0.5	RTP	G.729
Pair 3	Finished	50	10.5.0.1	10.5.0.5	RTP	G.729
Pair 4	Finished	49	10.5.0.1	10.5.0.5	RTP	G.729
Pair 5	Finished	50	10.5.0.1	10.5.0.5	RTP	G.729
Pair 6	Finished	50	10.5.0.1	10.5.0.5	RTP	G.729
Pair 7	Finished	50	10.5.0.1	10.5.0.5	RTP	G.729

Figure 20. The second test setup.

The MOS results are shown in Figure 21.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.729		**348**	**4,00**	**3,30**	**4,04**	**79,43**
Pair 1	Finished	49	4,00	3,43	4,03	79,44
Pair 2	Finished	50	3,99	3,40	4,03	79,28
Pair 3	Finished	50	4,01	3,56	4,04	79,53
Pair 4	Finished	49	4,01	3,55	4,04	79,53
Pair 5	Finished	50	4,00	3,42	4,03	79,43
Pair 6	Finished	50	4,00	3,40	4,03	79,48
Pair 7	Finished	50	3,99	3,30	4,03	79,30

Figure 21. Second test MOS results.

The average MOS of the seven simultaneous VoIP calls with two hops was 4.00. This result is lower than first result but is bigger than the minimum target.

3.4.3 The third test

The third test was carried out considering seven simultaneous VoIP calls in three hops from/to laptop (10.5.0.100) to/from node 5 (10.5.0.5) passing by nodes 1 and 3. The third test setup is shown in Figure 22.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.729		**344**				
Pair 1	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 2	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 3	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 4	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 5	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 6	Finished	49	10.5.0.100	10.5.0.5	RTP	G.729
Pair 7	Finished	50	10.5.0.100	10.5.0.5	RTP	G.729

Figure 22. The third test setup.

The MOS results are shown in Figure 23.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.729		**344**	**3,72**	**1,00**	**4,04**	**73,13**
Pair 1	Finished	49	3,70	1,00	4,04	72,61
Pair 2	Finished	49	3,72	1,08	4,03	73,36
Pair 3	Finished	49	3,72	1,00	4,04	73,15
Pair 4	Finished	49	3,70	1,00	4,03	72,87
Pair 5	Finished	49	3,71	1,00	4,04	73,00
Pair 6	Finished	49	3,73	1,00	4,04	73,32
Pair 7	Finished	50	3,74	1,00	4,04	73,59

Figure 23. Third test MOS results.

The average MOS of the seven simultaneous VoIP calls with three hops was 3.72. This result is lower than second result but is bigger than the minimum target.

3.4.4 The fourth test

The fourth test was carried out considering seven simultaneous VoIP calls in four hops from/to laptop (10.5.0.100) to/from node 6 (10.5.0.6) passing by nodes 1, 3 and 5. The fourth test setup is shown in Figure 24.

Group	Run Status	Timing Records Completed	Endpoint 1	Endpoint 2	Network Protocol	Script Filename
G.729		**328**				
Pair 1	Finished	46	10.5.0.100	10.5.0.6	RTP	G.729
Pair 2	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729
Pair 3	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729
Pair 4	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729
Pair 5	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729
Pair 6	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729
Pair 7	Finished	47	10.5.0.100	10.5.0.6	RTP	G.729

Figure 24. Fourth test setup.

The MOS results are shown in are shown in Figure 25.

The average MOS of the seven simultaneous VoIP calls with four hops was 3.62. This result is bigger than the minimum target.

Group	Run Status	Timing Records Completed	MOS Average	MOS Minimum	MOS Maximum	R-value Average
G.729		**328**	**3,62**	**1,00**	**4,03**	**69,94**
Pair 1	Finished	46	3,60	1,00	4,02	69,44
Pair 2	Finished	47	3,60	1,00	4,03	69,37
Pair 3	Finished	47	3,66	1,00	4,03	70,69
Pair 4	Finished	47	3,65	1,00	4,03	70,53
Pair 5	Finished	47	3,63	1,00	4,03	70,07
Pair 6	Finished	47	3,62	1,00	4,03	69,84
Pair 7	Finished	47	3,61	1,00	4,03	69,65

Figure 25. MOS results with four hops.

4 Conclusions

The Figures in the items 3.2, 3.3 and 3.4 shown that when then number of hops increases the MOS decreases as well, independently of the codec used. This is because the throughput for each node decreases with the number of nodes as $O(\frac{1}{n})$ [5], where n is the number of nodes in the ad hoc network.

According to the Figure 9, Figure 17 and Figure 25 and the minimum target MOS of 3.20, the maximum number of hops for seven simultaneous VoIP calls is four only when it is used the G.729 codec. When it is used the G.711 μ or G.726 codec, the maximum number of hops for seven simultaneous VoIP calls is three.

Although the G.729 packetization delay shown in TABLE III is the biggest, the simultaneous VoIP calls capacity with G.729 codec is bigger than G.711 μ and G.726 codec because the G.729 codec demands less throughput of the network. As throughput is a critical bottleneck in the ad hoc network due to the number of hops [5], this explains the reason of the best simultaneous VoIP calls capacity with G.729 codec.

5 References

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