QoS Considerations for 802.11 Networks

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Abstract

The paper describes some QoS evaluations for 801.11g networks. Since on any radio channel there are many factors contributing to the communication degradation it is quite difficult to provide an absolute mechanism for data flow committed throughput values as in wired networks. However, in specified environments some QoS like proprieties could be invoked under strictly defined conditions and they are described in the paper. Practical and comparative approaches are analyzed.
Keywords: *wireless communications, 802.11g standard, quality of services, throughput.*

1 Introduction

It is a well-known fact that in data transmissions on wireless computers networks the throughput (payload data rate), as main QoS parameter is quite different at the software application level than the reported equivalent speed on the communication equipment. For example, a wireless bridge working in 802.11b standard at 11Mbps will provide only 4-5 Mbps real speed at the OS interface while in 802.11g transmission only 22-24 Mbps are available. So usually less than half is useable. The available throughput is also related to many other factors so that many times there is a big problem to assure a quality data flow. Video transmissions or VoIP communication are some situations which needs some minimum QoS requirements. While in wired networks the bandwidth management can lead to specific quality data services in wireless networks this is very difficult because total available bandwidth is not a constant value depending on many factors as distance, radio propagation conditions, overlapping or clients' number and type.

In other words the speed calculated at the physical level (the lower level in OSI Model, usually known as bandwidth) is not the same as the data speed available at the highest communication levels (throughput). More, the data rate is not always a good measure for performance. The data rate is the number of data bits sent per second, but it only applies during the time that the frame is actually sent. There are lots of time when other stations are using the shared medium and possibly RF interference is causing supplementary delays. As a result, throughput corresponding to the data frame varies widely depending on utilization environment and is much lower than the data rate [3].

The phenomena are due to different factors as the following ones: channel noise, radio overlapping, bit stream overhead, modulation type and coding solutions, shared bandwidth.

The paper attempts to identify the best solution for evaluating the throughput as it is available at the application level, the optimum working conditions and based on that, the rules to be implemented in designing when specific QoS parameters are necessary. That is necessary since 802.11b/g standards have no QoS direct mode. Many applications involve quasi-continuous data flow. That can be obtain in ideal working conditions but practically, as briefly shown above, the are many factors associated with the throughput. However some QoS like rules can be highlighted.

2 The 802.11 QoS players

2.1 The payload

The body of the data frame carries information, such as TCP/IP and UDP packets. The payload size of the data frame body in 802.11 communications is always limited [4], which means that most information requires multiple data frames to carry the entire load. In fact, some applications as video streaming demands a continuous flow of data frames (to transport the moving pictures, for instance).

For example 802.11b has a maximum raw data rate of 11 Mbit/s and uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) media access method defined in the standard. Due to the CSMA/CA protocol overhead, in practice the maximum 802.11b throughput that an application can achieve is about 5.9 Mbit/s over TCP and 7.1 Mbit/s over UDP. 802.11g operates at a maximum raw data rate of 54 Mbit/s, or about 24.7 Mbit/s net throughputs, also like 802.11a [3].

2.2 Overlapping

Overlapping of radio channels is generating important data rate limitations due to the fact that one channel partially goes over another one. Overlap between the channels cause unacceptable degradation of signal quality and throughput. Basically 802.11b/g networks divide the spectrum into 14 overlapping, staggered channels having central frequencies at 5MHz distance specifying the center frequency of the channel and a spectral mask. However the energy of the channel extends further than these limits (±22 MHz from the center frequency). For channels supposed to not overlap (1 face to 6, figure 1) but even for channels at extreme distances, 1 face to 11 for example, there still is interference strongly related with the radio transmitting power on the involved channels. Lab tests shows that, throughput on a file transfer on channel 11 decreased slightly when a similar transfer began on channel 1, indicating that even channels 1 and 11 can interfere with each other to some extent [3].

The overlapping phenomena and its dependence with the transmitting power of neighbor channels make very difficult to rigorously define a data throughput, as a starting point for QoS discussions. Alternatively, the realistic evaluations are based on practical tests, worst-case estimation and statistical evaluation as we will see further bellow.

2.3 Radio bandwidth sharing

Since a radio AP usual works with many clients its maximum bandwidth will be shared between these clients working, obviously, on the same radio channel. With infrastructure wireless LANs, which include access points, data frames do not

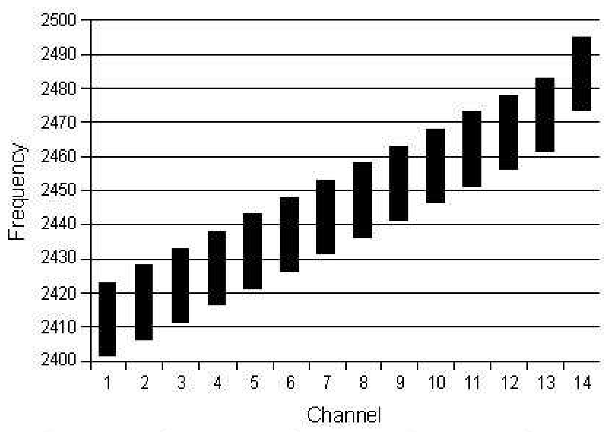

Figure 1: 802.11 Radio Channel Overlapping

travel directly between clients. Instead, a wireless client sends the data frame to an access point, and the access point then sends the contents of the original data frame in a different data frame to the receiving client. So the AP bandwidth is shared between the AP clients.

For fully demonstrate the throughput an AP with only one client has to be used, in other words ad-hoc like working mode is necessary. Data frames will travel directly from one ad hoc wireless client to another one.

2.4 RTS/CTS and legacy support

When 802.11g only AP/clients are used then the communication occurs at the highest possible TCP throughput. The AP instructs the network not to engage any protection method against 802.11b traffic and the maximum throughput goes to about 24Mbps for a 54Mbps bandwidth.

When in an 802.11g network the AP senses an 802.11b client, based on the imposed backward compatibility, it will try to manage both technologies and all 802.11g clients are instructed to use a protection mechanism. The effectively throughput decrease because there is extra information necessary to be carried. The maximum value becomes 15Mbps instead of 24Mbps, for a 54Mbps bandwidth channel when communicating with an 802.11g client and 5.8Mbps with 802.11b clients, at 11Mbps bandwidth [4].

RTS/CTS mechanism is the basic solution for managing 802.11b/g mixed wireless networks. One client is asking the permission for transmission sending a RTS message to the access point. At his turn, the access point is answering with a CTS message. Waiting for permission the client is not transmitting. Other clients receiving not-demanded CTS will also stop the send initiatives. Because like that the 802.11g clients are not transmitting simultaneously with 802.11g clients, this kind of collisions are avoided and the throughput is increased compared with no RTS/CTS solutions [5].

The 802.11b equipments are not able to detect when the radio channel is busy with 802.11g OFDM signals, except noise perception and can eventually asses that it has open condition to transmit. However 802.11g product still communicate but they have to periodically instruct the 802.11b to not transmit for a period of time allowing the OFDM messages to travel. This is generating signaling overhead. As result, the user available throughput is reduced.

Distance (m)	802.11b (Mbps)	802.11g (Mbps)		
		802.11g only	Mixed env. CTS-to-self	Mixed env. RTS/CTS
3	5.8	24.7	14.7	11.8
15	5.8	24.7	14.7	11.8
30	5.8	19.8	12.7	10.6
45	5.8	12.4	9.1	8.0
60	3.7	4.9	4.2	4.1
75	1.6	1.6	1.6	1.6
90	0.9	0.9	0.9	0.9

Table 1: Expected throughput for 802.11 environments

There are two available protection mechanisms, RTS/CTS and CTS-to-self. RTS/CTS procedure is similar with that used in wired transmissions and is based on the demand for transmission (RTS) and than wait for confirmation as clear transmission conditions (CTS). The CTS-to-self is based on the transmission of a CTS message at 802.11b rate (to be processed by all clients in the mixed wireless network) just to clear the channel followed by 802.11g data rate transmission. This mechanism will preclude 802.11b clients from transmitting simultaneously with an 802.11g client, thereby avoiding collisions that decrease throughput (due to necessary retries). However, the 802.11g with protection mechanism is lower but still higher than fully switching on 802.11b.

The table 1 bellow shows the expected maximum throughput for IEEE 802.11 environments [4].

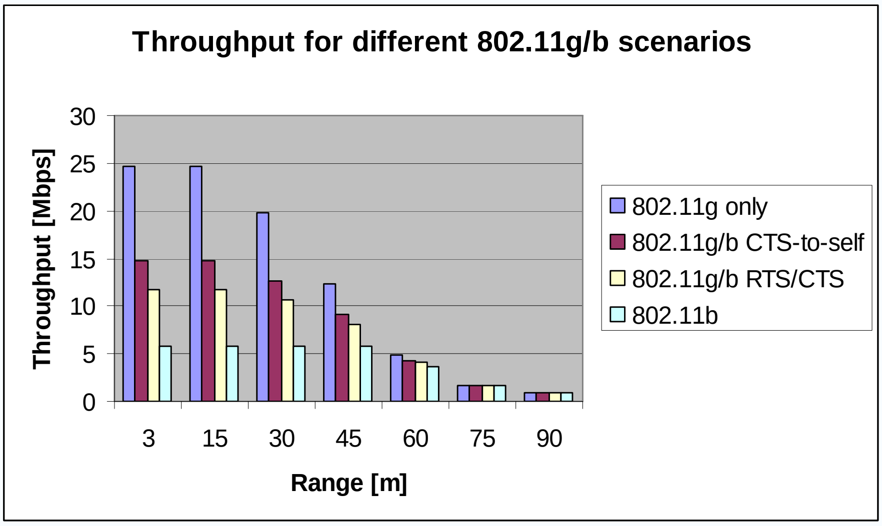

Figure 2: Throughput for different 802.11g/b scenarios

Scenario	Data Rate (Mbps)	Approximate Throughput (Mbps)
802.11b	11	6
802.11g/b (CTS-to-self)	54/11	13
802.11g/b (RTS/CTS)	54/11	8
802.11g only	54	22

Table 2: Experimental throughputs for 802.11 environments

The real throughput is even a little lower, basically due to the fact that is quite difficult to have a completely clear transmission media [5]. The lab tests show the maximum throughput as in table 2.

The use of RTS/CTS as a means of facilitating backward compatibility induces an extra network overhead as described. An important contribution to that is related with the back-off time [5]. The 802.11 network will adopt the higher-performance values (low ones, randomized) even that the back-off time values are imposed by 802.11b clients in mixed communications environments. As result, unpredictable data flow delays occur and they are very difficult to be managed based on standard QoS principles.

3 Theoretical approach

The available performances for 802.11g communications are directly related with the transmission type and used modulation and are reflected in so known PHY/MAC parameters. For 802.11g we can calculate the throughput as shown in literature [6]. Knowing that 802.11g is using 52 subcarriers, from this total number of 52 subcarriers/channel, 48 are carrying data, 4 of them being pilot subcarriers. Therefore there are 53 subcarrier frequencies but only 52 are used in a given single channel, with no subcarrier at the channel center frequency.

Based on the modulation type associated to every standard data rate, there are a number of coded bits per carrier depending on the level numbers of each modulation. For example 64-QAM is coding the 64 levels using 6 data bits since 2exp6=64 (see table 3). Because each symbol duration or interval is 4μs, than we can calculate that the number of symbols transmitted in one second is obtained as:
$N_S = 1/(4exp\text{-}6) = 250\ KSps$ (kilo symbols per second);
Having 48 carriers (generally N_C) and each of them carrying a N_B number of bits (column 5 in table 3) per symbol, now we can evaluate the total data flow as symbol rate (SR):

$$SR = N_C * N_B * N_S$$

For 64-QAM the result is: 48subcarriers * 6b * 1/4us/S = 72 MSps as symbol rate.

Since OFDM is invoking a FEC algorithm, a larger number of coded bits (coded symbols) are replacing a smaller amount of data bits resulting a rate knowing as FEC coding rate (column 7, table 3). For 64-QAM the result is 54 Mbps. This is the maximum standard data rate for 802.11g. For other modulations, the results are shown in the table 3.

4 Practical approach

4.1 Throughput

Due to the CSMA/CA protocol, some interrogations are necessary so that the informational payload is always less than the total amount of exchanged data, as described. For example, at the application level, in 802.11b communications, an application can achieve about 5Mbit/s over TCP and 7Mbit/s over UDP for an 11Mbps channel. The efficiency is 54% respectively 65%. Since usually a mixture of transport protocols are involved in carrying out the information an average value is more realistic. For 802.11g operating at a maximum raw data rate of 54Mbit/s, the corresponding net throughput is about 24Mbit/s. This means that less than 50% is really available. Laboratory tests performed by the author reveal the results from the table 4. In figure 3 the graphical variation is shown.

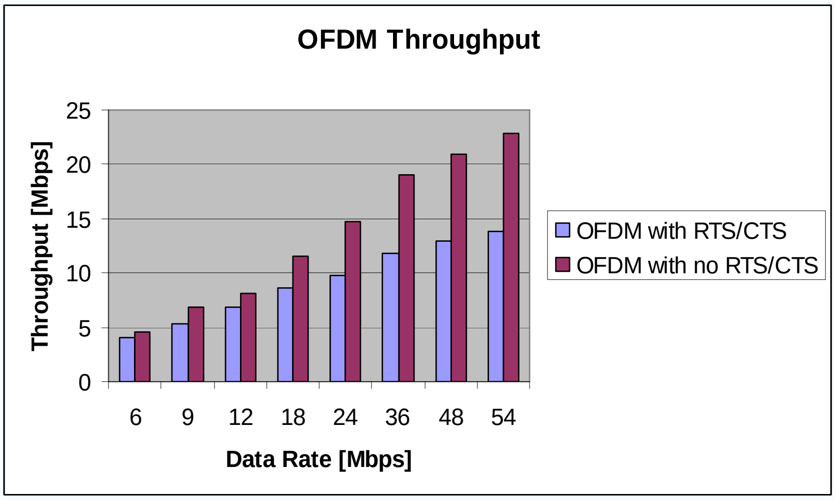

Figure 3: Experimental OFDM throughput short range indoor environment

We have to note the above transfer speeds are possible only if no other interferences occur (no overlapping, no significant radio attenuation, infrastructure mode with one client to avoid bandwidth sharing). In these ideal conditions the critical applications, like VoIP (as the most sensitive ones) can be performed theoretically allowing 11 to 15 VoIP streams for a 11Mbps channel. Commercial practical tests shows that only 6 to 7 streams are possible at medium load, depending on the involved equipment, evaluations being based on so known *R-value*, an ITU specification (G.107) for determining voice call quality [8].

4.2 Range and Coverage

The 802.11b/g standards define a limited radio output power for the transmitter. Related to that, there are some range and coverage limitations. A signal transmitted in a lower area of the frequency spectrum will carry further than a signal transmitted in a higher band. Additionally, a longer waveform (from lower band in the spectrum) will tend to propagate better through solids (like walls and trees) than a shorter waveform.

A fundamental rule is related with the fact that as data rates increase, range decreases. 802.11b uses DSSS to support data rates of 11, 5.5, 2, and 1 Mbps and 802.11g uses OFDM to support data rates of 54, 48, 36, 24, 18, 12, 9, and 6 Mbps. OFDM is a more efficient means of transmission than is DSSS, meaning that at a given range, higher OFDM-based data rates (802.11g) will be supported compared with DSSS-based data rates (802.11b).

Not only the transmit power is involved in range and coverage evaluation, but also the receiver sensitivity. The selection of either DSSS or OFDM transmission type has an effect on the maximum power the transmitter can use, as well as the capability of the receiver, particularly at higher data rates. That’s because higher data rates require a high degree of acuity on the part of the receiver. High power coming from the radio's transmitter tends to desensitize the receiver, a phenomenon known as Error Vector Magnitude (EVM). Consequently increasing the transmit power tends to decrease the range of the device. Several environmental factors can also have a dramatic impact on range and resulting coverage area.

Forcing the equipment to only work at a defined speed and not to connect at lower ones or watching at what distance the equipment is automatically switching its data rate, a coverage area for different data rates available in 802.11g communications was measured. The obtained results are shown in the table 5. Based on experimental data, in figure 4 are shown the throughputs versus coverage.

Data Rate (Mbps)	Transmission Type	Carrier	Modulation Type	Coded Bits per subcarrier	OFDM			Symbol Rate (Msps)
					Data Bits per OFDM symbol (n)	FEC coding rate (n/m)	Coded Bits per OFDM symbol (m)	
1	DSSS/CCK	Single	BPSK		-	-	-	1
2	DSSS/CCK	Single	QPSK		-	-	-	1
5.5	DSSS/CCK	Single	QPSK		-	-	-	1.375
6	OFDM	Multiple	BPSK	1	24	1/2	48	12
9	OFDM	Multiple	BPSK	1	36	3/4	48	12
11	DSSS/CCK	Single	QPSK		-	-	-	1.375
12	OFDM	Multiple	QPSK	2	48	1/2	96	24
18	OFDM	Multiple	QPSK	2	72	3/4	96	24
24	OFDM	Multiple	16-QAM	4	96	1/2	192	48
36	OFDM	Multiple	16QAM	4	144	3/4	192	48
48	OFDM	Multiple	64-QAM	6	192	2/3	288	72
54	OFDM	Multiple	64-QAM	6	216	3/4	288	72

Table 3: 802.11g transmissions proprieties

	DSSS				OFDM							
	BPSK	**QPSK**	**QPSK**	**QPSK**	**BPSK**	**BPSK**	**QPSK**	**QPSK**	**16QAM**	**16QAM**	**64QAM**	**64QAM**
Data Rate [Mbps]	1	2	5.5	11	6	9	12	18	24	36	48	54
Throughput RTS-CTS/CTS-self	0.9	1.7	4.2	7.1	4.1	5.3	6.8	8.6	9.8	11.8	13	13.8
Throughput No RTS/CTS					4.6	6.8	8.1	11.5	14.7	19	21	22.8

Table 4: Laboratory tests results for short-range open indoor environment

Data Rate [Mbps]	54	48	36	24	18	12	11	9	6	5.5	2	1
Range, 30mW with 2.2dBi gain diversity dipole antenna [m]	27	29	30	42	54	64	48*	76	91	67*	82*	124*

*802.11b fall back mode

Table 5: 802.11g/b ranges in an open indoor environment

The test/stress conditions were as bellow.
Radio: one radio client in Infrastructure mode, non-overlapping channels.
Traffic: mixed traffic with simultaneously ftp transfer, http download, video broadcasting at 320x240@20fps with medium compression from different local sources.
Packages medium composition: 99.4% TCP, 0.5% ARP, 0.1% UDP
Throughput measurement was done using freeware or open source software (Netmeter, Ethereal)
The equipments involved were USRobotics USR-8054, DLink DWL-2000AP+, Linksys WRT54g, Linksys WMP54g, Zyxel Zyair B-420, GlobalSun AP290FA8, GlobalSun GL2422AP.

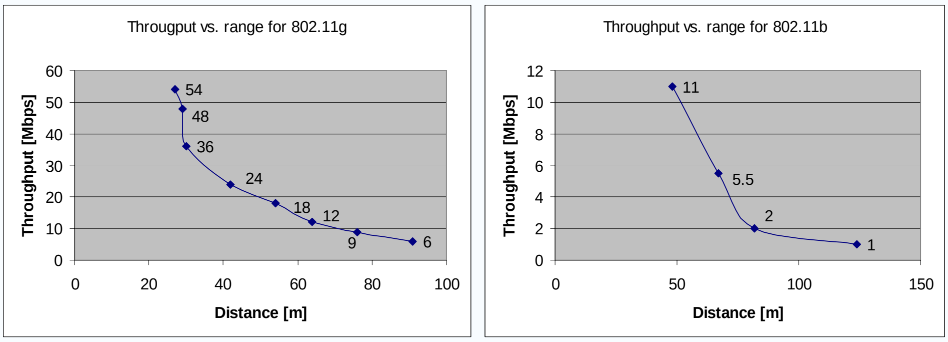

Figure 4: Experimental OFDM Throughput

5 Conclusions

Sending critical (as throughput and latency) data streams on wireless networks have a higher level of risk. Many up-to-date applications (VoIP, VoD/IPTV) require a real-time data streaming strictly defined at the level of bandwidth and latency (at least constant values are needed). That is due to the fact that any wired QoS mechanism is based on IP control at the transport level (TCP/IP) to assure a defined bandwidth for a certain service or user. Unfortunately, TCP/IP cannot guarantee this kind of purpose, it just make a best effort to do it. The wireless connections are defined at the physical level or MAC/PHY level (host-to-network level in TCP/IP model) so they are not "viewable" in the next level (Internet level, IP based), except for configuration issues and this is the point were the QoS problems arise. As the physical layer is a CSMA/CA radio environment, based on the principle "verify and transmit only when the channel is not busy" or "listen before talk", the data packets have to wait a non-deterministic time interval before being launched.

As shown in this article, in specified environments some QoS like proprieties could be invoked under the strictly defined conditions. The new 802.11e standard is already considering few rules at the radio level packet flow and that is expecting to allow some prioritizations by introducing priority levels at MAC/PHY level (basically thus stations with lower-priority traffic must wait longer than those with high-priority traffic before trying to access the medium). However many 802.11b/g equipments are already in use and pseudo QoS rules here presented became useful when critical data flow are associated.

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