Live Network Performance Challenge FLASH-OFDM vs. HSDPA

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Abstract

HSDPA networks are intensively being deployed to provide mobile broadband connectivity to mobile devices. In addition to HSDPA, FLASH-OFDM is another wireless broadband option operating in a licensed spectrum. However, if operated at very low frequencies like the network in Finland,, it is particularly interesting for emerging markets, especially for rural areas which are lacking telecommunications infrastructure. In contrast to the HSDPA standards, the FLASH-OFDM systems are proprietary. The market dynamics are very different between standardized and proprietary systems, sometimes causing extra challenges for the deployment of proprietary systems.

This paper provides quantitative measurements of the actual performance of two state-of-the-art live networks in Finland. The evaluation includes metrics such as throughput, delay, and VoIP quality considering network performance both on static and mobile scenarios. A commercial deployment evaluation is included in the analysis complementing the measurement data in order to provide a comprehensive view of the challenges.

Keywords- FLASH-OFDM, HSDPA, measurements, performance, VoIP

1. Introduction

There is an inevitable desire to increase capacity in all networks, both in fixed and wireless domains. In this article we address two wireless technologies haunting for more capacity: High Speed Downlink Packet Access (HSDPA) and Orthogonal Frequency Division Multiplexing (OFDM).

HSDPA [13][5] networks are intensively being deployed to provide broadband connectivity to mobile devices, such as handheld terminals and laptops. HSDPA is a direct evolution from the 3G network scenario, which makes its deployment very easy in order to support for wireless broadband accesses. Release 5 HSDPA equipment provides theoretical data rates of 14Mbps, and up to 7.2-10Mbps in practice. Future 3GPP releases will bring considerable performance upgrades to these networks, for instance, Release 6 introduces higher speeds on uplink (HSUPA) and lower latency, and Release 7 and beyond will introduce e.g. enhanced radio access technologies, such as orthogonal frequency division multiplexing (OFDM) and multi-antenna technology (MIMO).

HSDPA usually operates on the 2100 MHz frequency. However, it is possible to deploy HSDPA also on lower frequencies, such as 900MHz [11]. In Finland, this regulation has been already approved. Likewise, HSDPA is also being deployed at the 850MHz band in the USA and some parts of Asia, and Australia. High frequency bands suffer from higher attenuation and therefore, require more base stations than those deployed at lower frequencies. According to Holma [11], deploying HSDPA at 900MHz can provide 2.5 times larger cell area than deployments at 2100MHz.

On the other hand, FLASH-OFDM is a wireless broadband technology that can potentially provide nearly ADSL performance. This means that FLASH-OFDM can be a technological rival for ADSL, and in some cases, it may be the only feasible option to provide broadband access. FLASH-OFDM also operates on a licensed spectrum, but usually at lower frequencies than HSDPA (e.g. 450MHz). Due to the low frequency, a large coverage area can be achieved with a single base station. Thus, it is a particularly

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interesting option for emerging markets, and especially for rural areas that may lack other telecommunications infrastructure. However, at the 450MHz spectrum there is significantly less bandwidth than at higher frequencies. In Finland, only two 1.25MHz blocks are available for FLASH-ODFM. Therefore, while FLASH-OFDM operating at low frequencies can be feasible for rural and not very densely populated areas, it lacks the sufficient capacity for big cities.

We evaluated two networks in Finland. The HSDPA equipped network was assumed to be based on Release 5 equipment; operated by Elisa, which is Finland's largest cellular operator. The evaluated FLASH-OFDM network was recently deployed by Digita. The FLASH-OFDM network in Finland goes under the commercial name of "@450". It was opened to the public on April 1, 2007 and it is expected to cover the whole Finland by the end of 2009 [6][7]. This network is particularly interesting because it utilizes a recently reallocated spectrum. Likewise, Digita's attempt to cover the whole country in a short period of time brings additional interest. Emerging markets in particular, can follow with similar OFDM based wireless broadband deployments at low frequencies if they prove suitable in other countries. In our case, both networks were in Finland and therefore, the results are comparable in real-world environments.

This paper sets out to study the performance of two state of the art wireless broadband live networks, based on FLASH-OFDM and HSDPA competing technologies respectively. The key contributions of the paper are to evaluate and quantify some of the most relevant end user performance metrics, such as throughput, delay and VoIP quality in live scenarios for two wireless broadband technology offerings, FLASH-OFDM and HSDPA respectively. The evaluation considers network performance both in static and mobile scenarios. In addition, we also make a commercial comparison for both offerings advantages and disadvantages. As a result, we conclude that the analyzed technologies have characteristics that do not set one of them above the other. It is the desired performance or the use case that has to be considered when deciding for the optimal technology.

The remainder of the paper is organized as follows. In Section II we introduce the previous work in the topic, Section III describes our research approach, Section IV presents the results and analysis, in V we evaluate the advantages and disadvantages of both networks, and finally we provide our conclusions in Section VI.

2. Related Work

Due to the novelty of FLASH-OFDM network deployments, actual performance measurements in live networks are not widely available. Some of the few live FLASH-OFDM networks are T-Mobile in Slovakia [23], Citizens in Virginia USA [3], Digita in Finland [6], and DigiWeb in Ireland. While some other networks are planned, most of them are still on trialing phases or in the process of bidding for a spectrum license. Some performance metrics found in press releases are as follows. According to [1], expected data speeds are 1Mbps average in downlink and 300-500kbps average in uplink. Further, [24] claims the technology realizes typical downlink speeds of 1.5Mbps, with occasional bursts of up to 3Mbps, and typical uplink speeds of 375kbps, with bursts of up to 750kbps.

In regards to HSDPA performance, measurements conducted by Holma [12] evaluated Release 5 equipment in laboratory and field conditions. This study is directly comparable to our measurements for throughput and delay. However, these measurements do not consider VoIP quality performance, mobility scenarios involving multiple cells or HTTP browsing performance. Our measurements address these items and are conducted in a live commercial network rather than an experimental setup.

In addition, a number of simulation based studies on VoIP are available [26][2][18][21][27][15][8]. However, the simulations only provide a delay budget and focus on capacity rather than in providing a description of the end user experience. Contrastingly, our study focuses on end user experience and VoIP quality instead of delay budgets alone. Likewise, the delay budget used in the simulations is in several occasions modeled without accounting for the jitter buffer or encoding/processing delays [19][22][14][21][27]. Taking the jitter buffer play out delay implementation into account in simulations is very important since VoIP packets can arrive at different times. Also, due to the delay variations in wireless systems, unless a buffer is used, a large amount of packets would be lost. A conservative jitter buffer for wireless systems is 150ms [26]. Our study further extends VoIP performance by considering the jitter buffer and conducting actual measurements for VoIP. As for VoIP mobility in HSDPA, there is a simulation study aiming at determining the amount of possible lost frames of VoIP speech during mobility [25]. Finally, there are measurements focusing on indoor performance [16], and simulations for scenarios where HSDPA coexists with WCDMA and cell carriers are shared [20]. This last paper can be of interest, since our study was carried out in a network of similar nature.

3. Methodology and Test Environment

The evaluation methodology consisted of a variety of tests carried out in Digita's FLASH-OFDM and Elisa's HSDPA networks in Finland at different signal conditions. Our test objectives are the following:

a) Evaluation of generic network performance in terms of throughput, round trip time, HTTP (browsing), and VoIP performance with different signal quality levels
b) Evaluate the differences in performance under a mobility scenario in an area with good coverage as promised by the network providers
c) Determine the actual signal quality distribution in the test route

The test setup for static tests consisted of a laptop with either a FLASH-OFDM or HSDPA PCMCIA card. In addition, a 2dBi omni antenna was connected to the FLASH-OFDM card to improve sensitivity during mobility tests.

The FTP, Web and VoIP servers used for the tests were located in Finland. Throughput was measured via file downloads and uploads with 500KB, 1MB and 5MB files. VoIP quality was measured with a proprietary tool based on the E-Model [17][4]. The codec emulated was G.729 with a jitter buffer size of 120ms. Round trip time was measured with 32B, 256B and 1460B ICIMP echo request and reply (ping) packets. HTTP browsing was measured as page download times for 311KB web pages with cascade style sheets (CSS), which is representative of an average web page on the Internet. During mobility tests, multiple test executions took place consecutively. The test route had a length of roughly 15km, and the driving speed was 70km/h average. Finally, the subscriptions were a 1024/512 link for FLASH-OFDM and 2Mbps/384kbps for HSDPA. The testing took place during July and August 2007.

For FLASH-OFDM, the signal conditions were depicted by the PCMCIA card by two variables, signal power level, and signal to noise and interference ratio. Both variables were given as quality bars (0 to 4). We further define the signal quality as follows: Good signal (4 bars), Medium (2-3 bars) and Poor (0-1 bars). For HSDPA, signal quality was defined via measured Ec/N0 levels as follows: good signal (-3 to -5), medium signal (-7 to -9) and poor signal (-11 to -13). Ec/N0 indicates the received energy per chip divided by the power density in the frequency band. Ec/N0 calculation is depicted in equation (1), where RSCP is the received signal code power, P-CPICH is the received power level of the downlink primary common pilot channel, and RSSI is the received signal strength indicator.

$$Ec/N0 = \frac{RSCP_{P-CPICH}}{RSSI} \quad (1)$$

Ec/N0 values are an objective figure for quality conditions because they take into account both signal strength and the current interference level encountered in the cell.

A limitation of our study is that due to the nature of a live network, we are not able to know or control other user traffic taking place at the same time. Therefore, we cannot pinpoint the sources of e.g. a sudden quality drop or reduced bitrate. However, since we carried out multiple tests, our study provides a realistic view of the actual performance in the field. A second limitation was that we used slightly different antennas during mobility tests. Therefore, this gave an advantage for FLASH-OFDM. However, most FLASH-OFDM mobile scenarios are expected to have such an antenna, while HSDPA scenarios are not expected to have it.

4. Analysis and Results

The measurement results from our study are summarized in this section and subdivided by performance metric.

4.1. Throughput and HTTP browsing

The results show that high downlink throughput is possible with both systems (see Figure 1). However, HSDPA can reach higher throughputs due to its higher data rates. Likewise, HSDPA throughput is not affected much between good and medium signal conditions and has almost double the throughput than FLASH-OFDM during medium conditions. However, under poor signal conditions, throughput performance decreased for both systems, but still, HSDPA had higher throughput. In the uplink direction, both systems performed well and were able to achieve throughput close to the operator's offering, 512 and 384kbps respectively (see Figure 2). Since FLASH-OFDM has higher data rates on uplink, it has roughly a 100kbps throughput increase over HSDPA under good and medium signal conditions. However, under poor conditions both systems perform almost the same.

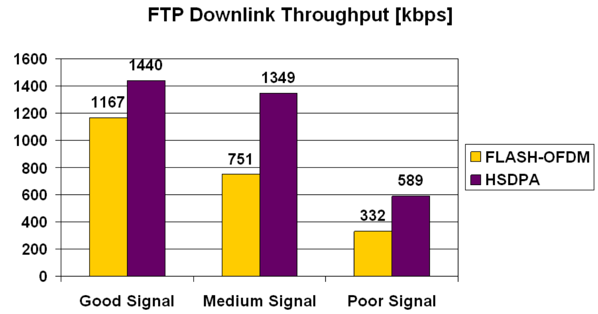

Figure 1. FTP throughput [downlink]

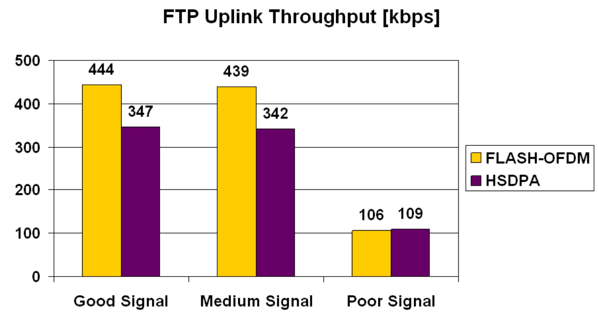

Figure 2. FTP throughput [uplink]

One interesting aspect with FLASH-OFDM was that small file downloads had higher throughput averages than larger files. The reason was that when a file downloading starts, throughput speeds might rise up to almost 2Mbps. However, after roughly 2 seconds, the throughput is settled to ~1Mbps, which is the operator's offering (see Figure 3).

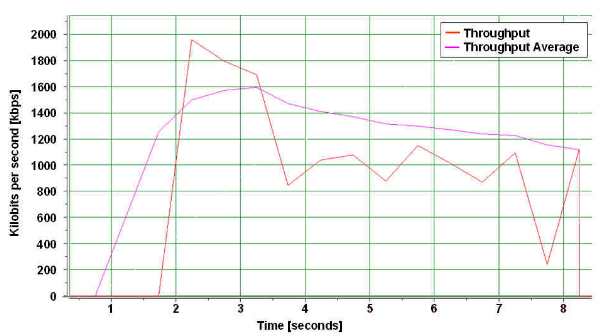

Figure 3. Example: FLASH-OFDM throughput during a 1MB file download

In regards to HTTP browsing, due to the high throughput of both systems, performance was relatively good (see Figure 4). The average page download time was between 4 and 6.7sec for good and medium signals respectively. However, the performance in poor conditions was substantially lower, between 11 and 15 seconds.

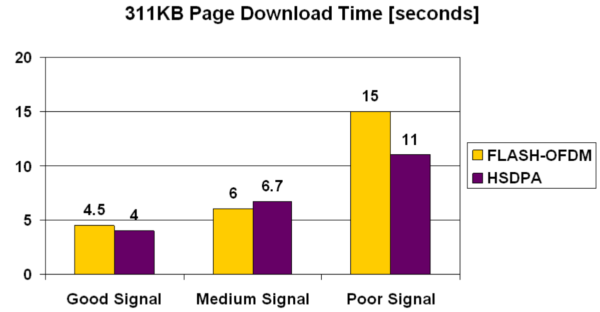

Figure 4. HTTP browsing page download times for a 311KB web page

During mobility tests, FLASH-OFDM throughput average was also high (750kbps). Additionally, the throughput distribution of the mobility test shows that 25% of the time throughput was 1Mbps or higher and only 25% of the time it was below 500kbps. In comparison, HSDPA performance is in average higher than FLASH-OFDM. HSDPA throughput average was 1110kbps. Moreover, throughput above 1Mbps was achieved more than 50% of the time, above 1.5Mbps 35%, and above 2Mbps 8%. Throughput below 500kbps happened only 20% of the time (see Figure 5 and Figure 6). Previous measurements [12] yielded similar results for throughputs up to 1Mbps. However, the live network measured in our study exceeds the distribution considerably for speeds above 1.5Mbps.

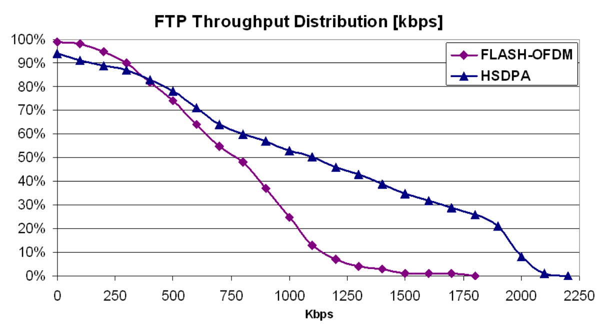

Figure 5. Throughput distribution during mobility tests

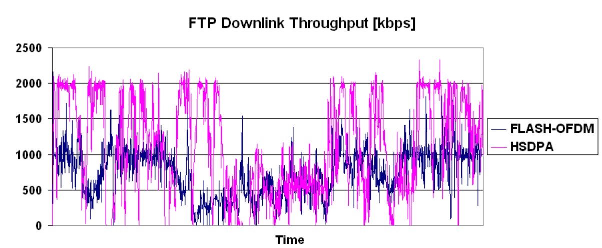

Figure 6. Throughput variation during mobility tests

In addition, during the mobile tests, we recorded the signal conditions to characterize the signal quality distribution along the test route for both systems. The measurements show that in general, it is highly probable to get a good signal level and that the coverage is well deployed. This also gives an additional insight of the high throughput experienced. Furthermore, in the case of FLASH-OFDM, poor signal was not experienced along the test route (see Figure 7). Figure 8 shows the signal quality distribution for HSDPA at a more detailed level.

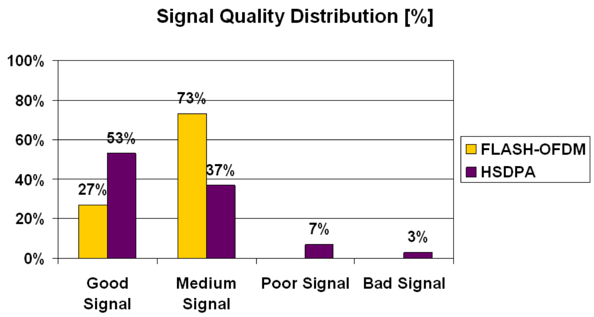

Figure 7. Signal quality distribution during mobility tests

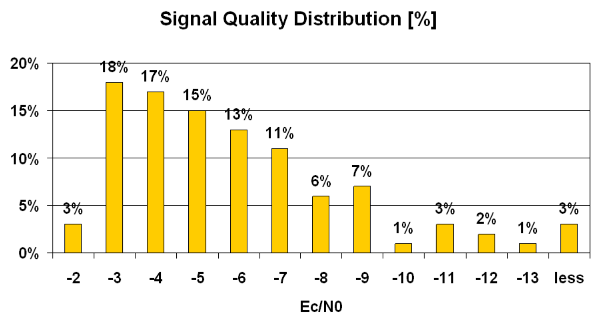

Figure 8. HSDPA detailed signal quality distribution

4.2. Round trip time

In static scenarios, the round trip time was in average 30-55ms for FLASH-OFDM and 120-140ms for HSDPA, and did not fluctuate much for 32 Bytes packets. As expected, larger packet sizes had an increased delay, particularly in poor signal conditions (see Table 1 and Table 2).

Table 1. FLASH-OFDM round trip time

Signal Quality	Average			Standard Deviation		
	32B	256B	1460B	32B	256B	1460B
Good	30ms	58ms	83ms	7ms	9ms	12ms
Medium	52ms	65ms	105ms	15ms	16ms	20ms
Poor	53ms	102ms	338ms	21ms	42ms	156ms
Mobile	48ms			20ms		

Table 2. HSDPA round trip time

Signal Quality	Average			Standard Deviation		
	32B	256B	1460B	32B	256B	1460B
Good	125ms	158ms	186ms	9ms	9ms	9ms
Medium	127ms	160ms	195ms	10ms	14ms	29ms
Poor	140ms	242ms	525ms	13ms	35ms	24ms
Mobile	190ms			281ms		

In mobile scenarios, delay is fairly stable for FLASH-OFDM. This is of particular importance for real time services such as VoIP which are affected by delay and jitter. In contrast, HSDPA had several delay peaks above 500ms along the test route, and thus, more sensitive to changes in signal quality (see Figure 9). Figure 10 shows a comparison of the delay distribution for both systems.

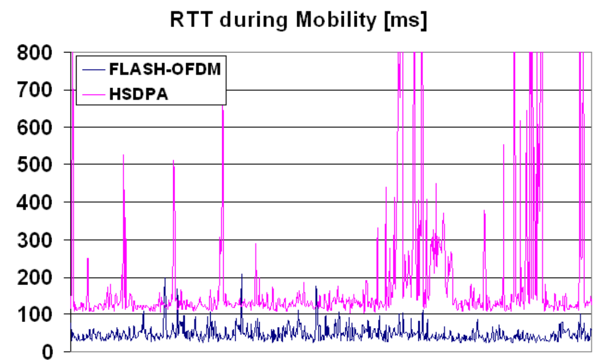

Figure 9. Round trip time variation during mobility tests

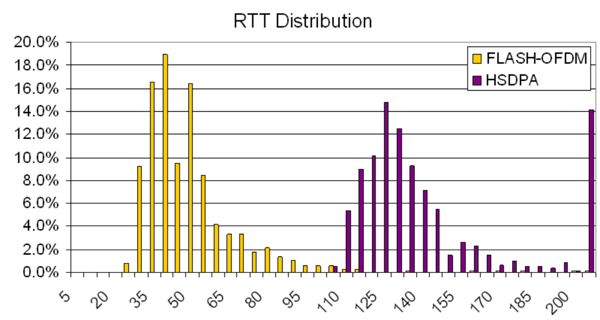

Figure 10. Round trip time distribution during mobility tests

4.3. VoIP quality

The VoIP quality results in static scenarios show that both systems are able to handle VoIP in good and medium signal conditions (see Table 3 and Table 4). In such cases, FLASH-OFDM is able to achieve call toll quality (MOS 4), while the quality with HSDPA is lower (MOS 3.5). In areas with poor signal, quality is roughly the same for both systems (MOS 3.3 and 3.4). The most noticeable difference between the static scenarios is the packet loss ratio, which increases as the signal quality decreases.

Table 3. FLASH-OFDM VoIP quality (G.729)

Signal Quality	Delay avg. [ms]	Jitter avg. [ms]	Packet Loss %	MOS
Good Signal (4 bars)	152ms	2ms	0	4
Medium Signal (2-3 bars)	153ms	3ms	0	4
Poor Signal (0-1 bars)	223ms	10ms	2.7	3.4
Mobile Scenario	180ms	12ms	0.05	4

Table 4. HSDPA VoIP quality (G.729)

Signal Quality	Delay avg. [ms]	Jitter avg. [ms]	Packet Loss %	MOS
Good Signal (Ec/N0 -3 to -5)	288ms	19ms	0.4	3.5
Medium Signal (Ec/N0 -7 to -9)	283ms	19ms	1.0	3.5
Poor Signal (Ec/N0 -11 to -13)	266ms	14ms	2.6	3.3
Mobile Scenario	331ms	22ms	1.93	3.2

For mobile scenarios, FLASH-OFDM performs remarkably well and is able to keep a steady high quality. In contrast HSDPA quality is lower than in static scenarios as we had expected from the results in section B. A mobile scenario obviously brings several additional challenges due to the different cell changes. The number of HSDPA cell changes along the test route was 28 and were characterized via the changes in scrambling codes used.

The low performance of VoIP in HSDPA mobility scenarios is due to the large amount of RLC retransmissions required. These are clearly shown in Figure 9. If RLC unacknowledged mode is used, the delay peaks could be reduced considerably. However, if this mode is used, there is also a possibility that the packet loss ratio will increase. Therefore, it is important to validate future results as well even if the feature is enabled.

The principle of operation in HSDPA [13] is such, that the BTS estimates the channel quality of each user based on the physical layer feedback on the uplink. Subsequently, link adaptation and scheduling takes place at a fast pace. When the packets are first received at the BTS, they are buffered. Then, the BTS transmits the packet; however, it will still keep it in the buffer. The reason being that in case of a failure in the transmission (e.g. decoding failure), a retransmission will take place directly from the BTS without requiring any action from the RNC. This is a powerful advantage since the retransmissions are combined at the terminal. However, if there is a physical layer failure, such as a signaling error, then an RLC retransmission is required, and packets are retransmitted from the RNC. This obviously results in an increase in delay, which is not beneficial for services like VoIP. While RLC retransmissions are not a very frequent event in HSDPA static scenarios, they are more likely in mobility scenarios. Figure 11 summarizes the BTS retransmission handling events.

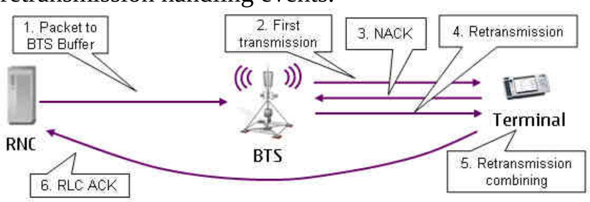

Figure 11. BTS retransmission handling

In the RLC unacknowledged mode, packets are not retransmitted even if some are lost, for example due to cell change operation. In these scenarios, packet loss can be minimized if the RNC accurately calculates when the handover will take place, and stop sending packets to the serving cell at the very last moment before it is replaced. [13]

As a remark, the VoIP results presented in this study are for laptop based VoIP communication. Therefore, even though jitter buffer delay is considered, the embedded VoIP client encoding and processing delays are not included. At the time of the study there were no available FLASH-OFDM handsets. Therefore, it was not possible to estimate processing delays accurately for this system. Likewise, it would not be fair either to use values from 3G handsets either since the software platform and operating systems can differ.

5. Commercial Deployment Evaluation

The FLASH-OFDM network in Finland is operated by Digita. However, Digita only takes care of the network and acts as a network provider. Thus, it supplies network capacity to operators. At the time of this study, there were only two FLASH-OFDM service providers, one focusing on the consumer segment and the other on the enterprise segment. Figure 12 shows the Digita's FLASH-OFDM network architecture.

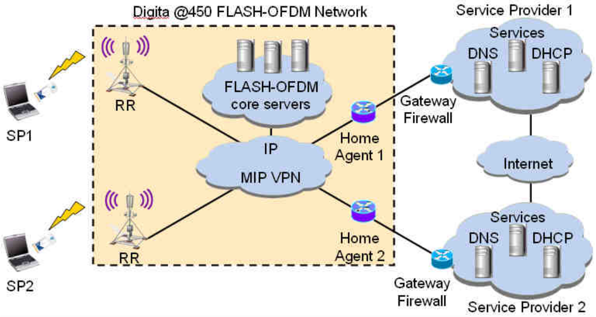

Figure 12. Digita FLASH-OFDM network architecture (modified from [10] with permission)

The commercial end user monthly offerings in Finland at the time of the study were as follows: (1) 29.90€ for 2Mbps HSDPA and 19.90€ for 1Mbps and, (2) 48€ for 1Mbps/512KB and 38€ for 512KB/512KB for FLASH-OFDM. From this comparison, FLASH-OFDM prices seem to be rather high for the service provided. Even if the link purpose was mostly for voice use, when compared to circuit switched price per minute (8€ cents) it is still not competitive. The price difference of 20€ accounts roughly for 237 minutes, which is above the average outbound call usage per subscriber per month in Finland (197 minutes) [9].

In regards to number of base stations required, low frequencies provide a significant advantage for large areas. This property is obviously most advantageous in rural deployments lacking telecommunications infrastructure. However, the bandwidth at 450MHz is considerably lower than higher frequencies. Therefore, in areas with more users, a cell that large might not provide enough capacity, and therefore, the lower attenuation is not necessarily an advantage anymore.

If we compare the feasibility of FLASH-OFDM over HSDPA deployments, we note that since all of the frequencies mentioned are licensed, the 450MHz spectrum in which FLASH-OFDM is most advantageous is not necessarily available or cheap. This spectrum as most others is subject to country regulations. Therefore, if deployed at a different frequency, the higher spectrum used for FLASH-OFDM, the lower competitive advantage it will have to HSDPA in regards to cost of deployment. Furthermore, since FLASH-OFDM is a proprietary technology, it has a lock-in factor, which limits the provider choices and terminal availability.

HSDPA is based on 3GPP standards, which results in a large number of providers and terminals. Moreover, further equipment releases will provide lower delays (65ms in HSUPA) and even higher throughputs. Likewise, even though HSDPA usually operates at 2100MHz, it can be deployed at 900MHz as well. Therefore, depending on the spectrum availability, several options exist, such as upgrading previous 3G networks, re-farming 2G to HSDPA or deploying HSDPA from scratch.

6. Conclusions

Multiple measurements were carried out to evaluate and characterize the performance of two live wireless broadband networks, FLASH-OFDM and HSDPA. The measurements show good performance in general. However, each system has its advantages and disadvantages. HSDPA is able to achieve higher throughput, and even higher with future releases. In contrast, FLASH-OFDM benefits from low and stable delay performance which results in the ability to support VoIP services with call tool quality in both static and mobile scenarios.

In regards to deployment feasibility, FLASH-OFDM frequency of operation makes it an option to be considered especially for emerging markets. In particular, rural areas lacking telecommunications infrastructure that can benefit from the large coverage areas achievable at low frequencies such as 450Mhz. However, this spectrum is licensed and therefore not necessarily available or cheap. Furthermore, since FLASH-OFDM is a proprietary technology, it has a lock-in factor, which limits the provider choices and terminal availability.

HSDPA is based on 3GPP standards, which results in a large number of providers and terminals. Moreover, further equipment releases will provide lower delays and even higher throughputs. Likewise, even though HSDPA usually operates at 2100MHz, it is possible to deploy at 900MHz as well. Therefore, depending on the spectrum availability, several options exist, such as upgrading previous 3G networks, re-farming 2G to HSDPA or deploying HSDPA from scratch.

In this paper we have compared the performance of two live state-of-the-art wireless broadband networks in both static and mobile scenarios. As a result of our study, we conclude that the analyzed technologies have characteristics that do not set one of them above the other. It is the desired performance or the use case that has to be considered when deciding for the optimal technology.

7. Acknowledgment

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