3G Femto or 802.11g WiFi

Which is the Best Indoor Data Solution Today?

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Abstract—In this paper HSPA Release 6 femto and IEEE 802.11g WiFi indoor data solutions are investigated from an end user perspective. Femto and WiFi access points are deployed at typical locations in an urban environment and end user performance is measured. Three key performance indicators (KPI) were defined - downlink and uplink user data rates, latency and mobile power consumption. These three KPIs are of high importance when choosing an indoor data solution. Our measurements show that the downlink and uplink data rates of the WiFi solution are significantly higher than femto data rates. Similarly, latency results show that WiFi outperforms the femto solution. Especially, the radio resource control (RRC) connection set-up time increases the latency for the femto. In terms of idle power consumption the best results are obtained when the mobile camps on the femto. Whereas, WiFi performs best in all active mode power consumption measurements. Based on our KPIs, the preferred indoor data solution today is WiFi. The deciding factor is the combined latency and power performance of the WiFi, where WiFi outperforms the femto.

I. INTRODUCTION

In 2012 mobile data traffic grew 70% and 33% of the traffic was offloaded onto fixed networks through WiFi or femto cells [1]. These numbers show that indoor networks already play an important role in the wireless communication world today. In addition the share of mobile data traffic offloaded by WiFi or femto cells is expected to increase even further, up to 46% in 2017. Consequently, indoor small cells have received plenty of attention in academia and open literature [2] [3]. Both technologies are low cost solutions to improve indoor data capacity, usually deployed by the end user, and connected to public Internet. Despite the similarities there are also some fundamental differences. Whereas, the WiFi access point is a standalone device, the 3G femto access point connects to a femto gateway. The femto gateway acts as a femto concentrator towards the cellular core network and for configuration of femto access points. Hence, the femto solution is more complex than the plug and play WiFi solution. Though, for an end user the femto and WiFi installation procedure is identical. In terms of spectrum, the femto solution requires licensed spectrum where the WiFi solution utilizes unlicensed spectrum.

Achievable downlink and uplink user data rates are important in marketing and adaptation of wireless communication technologies, and user data rates have also been studied in several papers, both in terms of system simulations and measurement campaigns. For example, the measurements in [4] concludes that femto HSDPA data rates are up to five times higher than macro HSDPA data rates.

The importance of low latency should not be neglected. In [5] it is studied how increased website loading delays affect the users experience. Delay is the time from the user is clicking on a hyperlink to the time the web page is loaded. The authors conclude that website delays should be kept under 4 seconds. Otherwise, users tend to stop using the website. The authors of [6] conclude that for simple tasks on the internet, the delay should be less than 2 seconds. None of the delay studies specify any access technology, but they clearly indicate the maximum expected delay when dealing with internet services and applications. In [7], 3G femto round trip time is measured to approximately 130 ms. But it is not measured how the RRC connection set-up procedure effects the overall femto latency.

Mobile power consumption has also been studied extensively as it is part of the overall user experience. In [8], the power consumption when connected to 3G macro and WiFi is measured. It is concluded that the tail energy overhead is significant in 3G, because the mobile is kept in high power states after data transfers are completed. A similar conclusion is reached in [9].

This paper contributes with an indoor 3GPP Release 6 femto and 802.11g WiFi measurement campaign performed in realistic environments and for applicable use cases. Our objective is to determine which is the ultimate indoor data solution today from an end user perspective. For an end user the important key performance indicators (KPI) are: user data rates, latency, and mobile power consumption. Previous studies have mainly focussed on the KPIs independently or for a single technology only. We are measuring all KPIs for both femto and WiFi, including the interaction between the different KPIs. And based on the outcome, we conclude which is the best indoor data solution today.

Section II introduces the measurement scenarios and measurement equipment, followed by measurement methodology in Section III. In Section IV, the measurement results are presented, and finally, Section V concludes the paper.

II. MEASUREMENT SCENARIO AND EQUIPMENT

Two measurement scenarios are chosen; a typical enterprise scenario and a typical apartment scenario. Common for both measurement locations is an overlay live macro network with inter-site distances of a few 100 meters. At both locations the macro network supports HSDPA dual cell, resulting in a DL bandwidth of 10 MHz. The surroundings are characterized by typical urban building constructions. At both measurement locations, indoor macro coverage is sufficient for both voice and data services, so an indoor data solution should provide
higher data rates and increase the network capacity.

A. Enterprise Environment

The first measurement location is a 3-floor office building with a ground area of approximately 15 m x 45 m. Inside, 20 offices and meeting rooms are connected by a single corridor. During the measurement campaign, a WiFi or a femto access point is deployed in an office in the middle of the corridor at ground floor. Hence, the femto and WiFi access points provide indoor coverage to offices 25 meters away. Measurements are performed in all the accessible offices and meeting rooms at ground floor. Outside the building, the serving 3-sector macro site is located approximately 150 meters away. In previous measurement campaigns, the building penetration loss has been measured to approximately 20 dB at 2 GHz [10] and the indoor macro received signal code power (RSCP) is ranging from -90 dBm to -65 dBm. Finally, it is noted that a planned indoor WiFi network is already deployed in the building and is active during all measurements. Therefore, it is not possible to select a non-interfered WiFi channel for the measurements. This location is referred to as Enterprise location.

B. Home Environment

The second measurement location is in a residential area with surrounding apartment building blocks of up to 5 floors. The area of the apartment is 60 m² and consist of 5 rooms and is located at the third floor in a 5-floor building. Due to installation constraints, the femto and WiFi access points are deployed in the corner of the apartment and the coverage radius is up to 10 meter. During the measurement campaign, indoor cellular service was provided by an outdoor 3-sector macro site located approximately 150 meters away from the apartment. The indoor RSCP is in the range -80 dBm to -70 dBm. Since it is a residential area, there is no coordination of the WiFi access points deployment. Consequently, the number of visible WiFi networks is approximately 10, and depends on the exact location in the apartment. For the measurement campaign the WiFi channel with the best quality is chosen, which is the channel with the lowest interfering RSSI level. This location is referred to as Home location.

C. Measurement Equipment

The femto access point is an IP Access E16 and is UMTS/HSPA 3GPP Release 6 compliant. During measurements, the total wideband transmission power of the femto access point was manually configured to +24 dBm and the common pilot channel (CPICH) power to +14 dBm. HSDPA dual cell is not supported by the femto. The femto is co-channel deployed with the existing macro network and connects to a femto gateway in the cellular core network. Two different WiFi access points were used at the two locations. Both are IEEE 802.11g compliant. The WiFi total transmit power is set to +16 dBm. Table I lists the femto and WiFi specifications.

At both locations, the same backhaul is used for the femto and WiFi access points. The backhaul performance was measured, and the results are presented in Table III in Section IV.
Where $R$ is an average Danish household. Therefore, similar results are to be expected and UL data rates in Denmark were 20.4 Mbps and 1.9 Mbps, respectively [13].

In the first half of 2013 the median DL data rate are significant higher than the Home data rates. Though, it is presented in Table III. It is seen that the Enterprise data rates are lower due to increased number of interfering WiFi networks. The maximum femto DL throughput measured is approximately 4 Mbps. Based solely on achievable user data rates, WiFi is the preferred solution. However, the comparison is not fair. First of all, the DL transmission bandwidth of the femto is only 5 MHz, whereas for macro the DL transmission bandwidth is 10 MHz due to the HSDPA dual cell. For WiFi the transmission bandwidth is 20 MHz, shared between DL and UL. The spectral efficiency (SE) for macro, femto and WiFi is close to 0.5 bps/Hz, except WiFi at Enterprise where WiFi differs from the others with a SE of 1.5 bps/Hz. This is due to less interfering WiFi networks and is in general accordance with the conclusion from [14]. Therefore, when comparing the DL spectral efficiency, WiFi performs best if only single user and a few interfering WiFi networks are present, e.g. in a planned WiFi network environment. Otherwise, there is no particular difference between the achievable femto and WiFi user SE. Despite the higher femto RSCP the macro and femto SE are similar because femto only supports 16 quadrature amplitude modulation (QAM).

### TABLE III. BBACKHAUL PERFORMANCE AT ENTERPRISE AND HOME. MEASURED VIA WWW.SPEEDTEST.NET.

<table>
<thead>
<tr>
<th></th>
<th>DL</th>
<th>UL</th>
<th>RTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise</td>
<td>61 Mbps</td>
<td>33 Mbps</td>
<td>13 ms</td>
</tr>
<tr>
<td>Home</td>
<td>16 Mbps</td>
<td>2.8 Mbps</td>
<td>23 ms</td>
</tr>
</tbody>
</table>

### A. User Data Rates

Figure 1 shows the measured DL data rates at Enterprise and Home. It is seen that the WiFi at Enterprise performs best by a large margin. Even at the offices at the ends of the corridor (more than 20 meter away from the WiFi access point) the DL throughput is 5 Mbps. Despite the coverage area of WiFi at Home is smaller, the achievable data rates are lower due to increased number of interfering WiFi networks. The maximum femto DL throughput measured is approximately 4 Mbps. Based solely on achievable user data rates, WiFi is the preferred solution. However, the comparison is not fair. First of all, the DL transmission bandwidth of the femto is only 5 MHz, whereas for macro the DL transmission bandwidth is 10 MHz due to the HSDPA dual cell. For WiFi the transmission bandwidth is 20 MHz, shared between DL and UL. The spectral efficiency (SE) for macro, femto and WiFi is close to 0.5 bps/Hz, except WiFi at Enterprise where WiFi differs from the others with a SE of 1.5 bps/Hz. This is due to less interfering WiFi networks and is in general accordance with the conclusion from [14]. Therefore, when comparing the DL spectral efficiency, WiFi performs best if only single user and a few interfering WiFi networks are present, e.g. in a planned WiFi network environment. Otherwise, there is no particular difference between the achievable femto and WiFi user SE. Despite the higher femto RSCP the macro and femto SE are similar because femto only supports 16 quadrature amplitude modulation (QAM).

The measured UL throughput is shown in Fig. 2. Again, it is seen that the WiFi performance is significantly higher at Enterprise than the rest. It is also seen that the WiFi throughput at Home is limited by the backhaul throughput (2.8 Mbps). The femto UL throughputs are practically independent of the location. Similar to the DL, an end user would prefer the WiFi solution due the experienced data rates. Also, when comparing the UL SE WiFi performs best with a SE of more than 0.24 bps/Hz compared to less than 0.13 bps/Hz for femto. This number might seem low, but one should keep the maximum theoretical SE in mind, as this is only 0.29 bps/Hz due the quadrature phase shift keying (QPSK) modulation limitations.

### B. Latency

Next, the femto and WiFi latency is compared. Table IV shows the latency for the Enterprise location with a ping interval of 2 seconds. Backhaul performance is included as upper bound reference with an average latency of 24 ms. The
WiFi latency is the best with an average of 44 ms, and is quite consistent with a minimum measured latency of 36 ms and a maximum of 47 ms. Whereas, the average latency of the macro and the femto solution is approximately the double of the WiFi and just below the 100 ms mark. The maximum latency of the macro and the femto is 119 ms and 112 ms, respectively. These results are similar to those reported in [7].

At Home, the WiFi and macro latencies are reduced while the femto latency is increased, see Table V. Still, the latency is not a big differentiator between the wireless solutions, and well below the acceptable limits from [5] and [6].

Table VI lists the latency results for ping intervals of 10 seconds at Enterprise and Home, respectively. These results are similar to those reported in [7].

**C. Mobile Power Consumption**

Table VII presents the power measurement results. In idle and screen OFF, the WiFi power consumption is approximately 22 % higher than the femto power. With the screen ON, WiFi power is only 7 % higher than femto, since the screen/CPU is now the major contributor in terms of power consumption. In theory, with screen OFF and in idle mode, the battery would last 4 days and 7 hours with femto, and 3 days and 12 hours with WiFi. Battery capacity is 7.8 Wh.

Table VII presents the power measurement results.

Comparing the web browse test cases show that WiFi performs best. The web browse 15 second test case show that the femto power is approximately 45 % higher than WiFi and 51 % higher in the web browse 45 second test case. The reason for the high femto power is that the mobile is kept in RRC_connected mode (CELL_DCH, CELL_PCH, or CELL_FACH) after the web pages are loaded, whereas the mobile returns faster to the idle power level when connected to WiFi. Also, WiFi is almost 10 times more energy efficient compared to femto in the FTP DL test.

In idle mode the power consumption is lowest when the mobile is camping on the femto, otherwise WiFi performs best. For an end user this means, that WiFi delivers the best power performance if the specific mobile is used more than approximately 30 minutes per day. Using a femto and considering the web browse model where a website is loaded every 45 seconds the mobile battery lasts for 4 hours and 30 minutes. Using WiFi, the battery lasts almost 7 hours.
D. Result Discussion

Based on the DL and UL experienced data rates, WiFi is the preferred indoor solution from an end user point of view. This is mainly due to the wider transmission bandwidth of the WiFi system and support of higher modulation. However, even when comparing the spectral efficiency, WiFi performs best. Especially, if the WiFi network is not interfered by other WiFi networks. The experienced data rates would be higher, if the tested WiFi equipment was IEEE 802.11n/ac compliant. Similar, a HSPA Release 7 compliant femto could also improve the experienced femto data rates and spectral efficiency as HSPA Release 7 supports higher modulation than HSPA Release 6.

Our latency measurements showed that this is the main disadvantage of the femto solution. The measured femto average latency was longer than 3 seconds if the mobile was not kept in CELL_DCH state during ping intervals. Such latency is simply too long compared to end user expectations, and considerably shorter latencies are expected in wireless communications systems today. For comparison, the WiFi latency was below 50 ms. If the mobile was kept in CELL_DCH mode, the femto latency is approximately 100 ms. However, the power consumption in CELL_DCH is higher than in idle [8]. Therefore, configuring the inactivity timers is a trade-off between perceived user performance and mobile power consumption. Potentially, 3GPP LTE femto cells could improve the femto latency [16]. Field trials have shown that latency for macro LTE networks are lower compared to macro HSPA networks [17][18].

The lowest idle mode power consumption was achieved when the mobile was camping on the femto. WiFi power consumption was 22 % higher. During the web browse sessions the mobile’s average power was lowest for WiFi. In femto and macro networks the mobile stays in the high power RRC states after the data transmission is completed. For end users, this means that if the mobile is used for web browsing more than 30 minutes per day, WiFi is the best solution in terms of power consumption. WiFi also showed the best power efficiency in the FTP file download test.

Basically, our measurements show that WiFi provides better latency and active mode power consumption than the femto, regardless of the femto RRC configuration. Increasing the RRC inactivity timers would reduce the femto latency at the expense of increased mobile power consumption. Decreasing the RRC inactivity timers reduces the power consumption but increases latency.

V. Conclusion

Increasing mobile data volumes and user expectations encourage the deployment of indoor small cell networks. Femto and WiFi solutions are two strong candidates for present and future indoor data networks. An indoor femto (3GPP Release 6) and WiFi (IEEE 802.11g) measurement campaign was carried out to conclude which solution is preferred the indoor data solution today for an end user.

Three key performance indicators were identified: user data rate, latency, and mobile power consumption. Based on our key performance indicators, WiFi is the best indoor data solution. WiFi offers higher data rates, lower latency and lower active mode power only at the cost of a slightly higher idle power compared to femto. The major femto disadvantage was high latency due to required RRC state transitions. Our measurement results also showed that the femto RRC set-up has a huge impact on both latency and power consumption. It was not possible to find a compromise where femto outperforms WiFi in latency and power consumption.

In the future, WiFi 802.11ac and 3GPP LTE will be the de facto WiFi and cellular standards. Further research is necessary to determine the performance improvements introduced in the aforementioned standards.

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REFERENCES