Mobile IP as an Enabling Technology for VoIP in Metropolitan Wireless Mesh Networks

Andres Arjona
Nokia Siemens Networks
andres.arjona@nsn.com

Antti Ylä-Jääski
Helsinki University of Technology
antti.yla-jaaski@hut.fi

***Abstract*—Metropolitan wireless mesh networks are being deployed to provide broadband connectivity to city-wide hotspots. However, its commercial feasibility and business model have not yet proven successful. In particular, deploying large areas with good signal coverage is very difficult. The main problem is a result of the number of required nodes to cover an area with proper signal strength that can support services such as VoIP. Unfortunately, as the number of nodes increases, so does the cost of deployment. In an environment for which the economical model has not been proved, increasing the cost of deployment is not feasible. However, by the use of Mobile IP, it is possible to interwork with other networks. In this way, users can roam to other networks with broader coverage (e.g. 3G) in places where wireless mesh coverage is no longer available or suffers from coverage gaps.**

This paper, underlines the actual performance of the Mobile IP solution via actual measurements with available commercial handsets. The focus is on the feasibility of using VoIP services over wireless mesh networks and interwork with 3G networks. The results show that even though the performance is not yet optimal, it is ready for a service rollout under proper conditions. In particular, a good service offering can encourage users to make use of this technology despite the performance limitations.

Keywords- wireless mesh, VoIP, mobile IP, interworking, 3G, WCDMA

I. Introduction

Over the last few years, wireless mesh networks that provide WiFi services over large areas, including entire municipalities have been successfully deployed. Many vendors have proposed products and solutions to provide wireless broadband connectivity over extended areas. [4][16][17][18][21]

The mesh network is composed of three basic elements: an 802.11 WiFi client, such as a laptop or VoIP phone, for the end user to connect to the network; an access point (AP) for the client to attach to; and some mesh routers form the backhaul of the mesh network (see Figure 1)

This research was partially supported by the Telecommunications Software and Multimedia Laboratory at Helsinki University of Technology

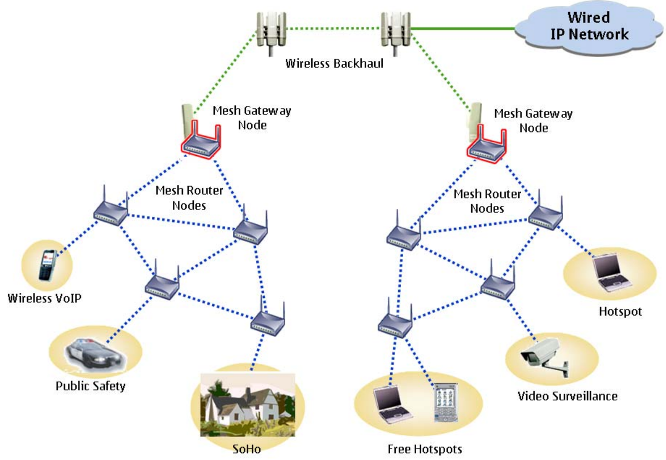

Figure 1. Metropolitan Wireless Mesh Network Architecture

Metropolitan wireless mesh networks are seen as a potential disruption to cellular operators, by providing VoIP services to mobile handsets ubiquitously in a wide city-area. As such the performance of VoIP connections is critical to the commercial success of these mesh networks.

Despite all the movement and enthusiasm created by the deployment of these networks, they are still to be proven commercially successful. Moreover, in regards of the feasibility of using them as an alternative for voice services is very doubtful with the current deployment node density. Current rule of thumb for metropolitan wireless mesh network deployments state that an average of 30 access points is required to cover a square mile (2.56 square kilometers). Thus, if all access points cover a circle of equal size, and are placed in the plane according to the triangular paving (hexagonal cell coverage) then each coverage disk is about 166 meters apart. Research in [2][20] show that this current rule of thumb is not adequate and is unable to provide signal coverage, and that it is possibly a consequence of the 100,00USD common cost per mile budget.

In order to provide VoIP services, the WiFi signal must have a signal to noise ratio above 18dB and preferably above 25dB. Otherwise, the link quality is not good for VoIP services due to the increase in packet loss. In order to provide such coverage, the node density would be almost triple than the current rules of thumb (100,000USD cost per mile with 30 nodes), and thus is not economically feasible. Figure 2 shows a signal coverage map of the Google WiFi mesh network in Mountain View.

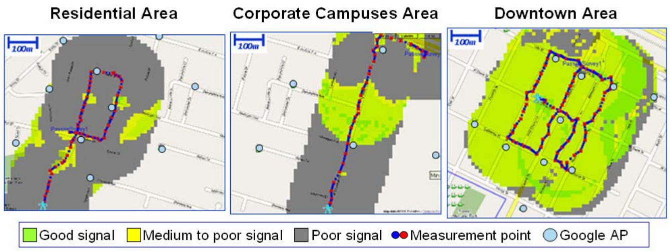

Figure 2. Signal Coverage in the Google WiFi Mesh Network in Mountain View

This paper sets out to study the performance and feasibility of using Mobile IP [19] as a building block for VoIP. The motivation is to extend WiFi coverage and provide interworking between metropolitan wireless mesh networks and 3G. The measurements are carried out with actual handsets, embedded VoIP clients, Internet VoIP servers and Mobile IP Agents. The main contributions are a performance evaluation of the solution in a real life scenario. Likewise, the results are compared with other existing solutions such as UMA. Based on the analysis of the measurements, the implications and potential benefit of using Mobile IP are concluded.

The remainder of the paper is organized as follows. In Section II we introduce the previous work in the topic, and Section III describes the main use case. In Section IV we describe the research approach, Section V presents the results and analysis, and finally conclusions are described in Section VI.

II. Related Work

There are a few papers depicting the actual performance in live metropolitan wireless mesh networks. Research in [2][20] made an evaluation of the Google mesh network in Mountain View. An evaluation of VoIP services is also included in [2]. Additionally, [20] evaluated the network performance (but not VoIP) on the MetroFi mesh network, also located in Mountain View. Both networks utilize different vendor equipment [17] [21] and have slightly different architectures. Regardless of this, the overall conclusion is the same, with the current cost per node, deploying mesh networks with suitable coverage for VoIP is not commercially feasible and is in fact much more expensive than deploying cellular networks.

In regards to Mobile IP performance and disruption time, there are many papers available based on simulations [7][14][15]. Most of these papers consider the delay between the mobile node and the mobile IP agents for the calculations, while some also account for the wireless link delay as well. Moreover, research in [6] outlines the differences in performance between the MIPv4 and MIPv6 schemes. However, empirical data that supports the simulations is not widely available. Some papers such as [23] provide measurements from an actual implementation. In regards to measurements of VoIP between WiFi and 3G the available research is even scarcer. The most closely related work is [11], which provides mobility measurements between GPRS and WiFi. The setup was a laptop with a Mobile IP client streaming packets similar to VoIP packets during mobility, and used the Dynamics Mobile IP implementation [12][13]. It must be noted though that since no actual voice packets are transmitted, neither encoding/decoding nor packet loss concealment algorithms are in place either. Their results show that seamless mobility (no noticeable break) is possible, except in cases were radio resources from the cellular network are released. In such cases, the data outage is of approximately 2.5sec.

Finally, [3] shows that the UMA solution (also based on Mobile IP) is also able to provide seamless mobility between cellular (2G) and WiFi networks. However this is not a native VoIP solution and involves transcoding between circuit and packet switched voice. Voice breaks are roughly 30ms when moving from GSM to WiFi, and below 200ms when moving from WiFi to GSM. It must be noted though, that the UMA solution has a slightly different architecture and purpose than native Mobile IP solutions in the sense that it is envisioned as a way of extending GSM coverage.

Our research extends the available research considerably by including actual measurements with commercial handsets, embedded VoIP clients, Internet based VoIP servers and Mobile IP agents, and by comparing the results with the available research. Therefore, our research provides a real insight of what the actual performance can be if Mobile IP is rolled out as an enabling technology for VoIP in wireless mesh networks.

III. Main Use Case

To outline our main use case, let us assume a user with broadband connectivity and an access point connected to the Internet. Under these circumstances VoIP over WiFi is possible at very low prices. VoIP over WiFi is the solution of choice at home because it can provide good performance and coverage indoors. In contrast, metropolitan wireless mesh networks usually have an almost inexistent coverage indoors and therefore, are not suitable for providing VoIP at home. As for cellular data, the signal strength indoors might not be optimal for carrying VoIP either. Particularly in countries like the United States and Japan, good cellular indoor coverage is not always available even for circuit switched calls, therefore, even less likely for packet switched services. UMA [3] is a good example of how an access point at home can be used as an extension of cellular networks. Therefore, we consider the use of VoIP over WiFi via a home access point as the main choice at home.

When moving outdoors, there are two main possibilities, having wireless mesh coverage and having cellular coverage. However, if a VoIP call started at home, it will drop as soon as the signal decreases when the user leaves the facility. There is no interworking between the network at home, the wireless mesh network or the cellular network because they all use different IP addresses. The same situation occurs if the user started the call outdoors and moved indoors, or if it started the call in the wireless mesh network and moved to an area without enough coverage. With Mobile IP, the VoIP call can be transferred to one of the newly available networks and thus enable VoIP continuity. If there is a known Home Agent in the Internet and the VoIP handset has a configured Mobile IP client, the Mobile IP procedure in a VoIP call would be as follows: (1) Clients register to a VoIP server via the Internet using their home IP addresses (IP A & IP B); (2) Clients can call each other using the Internet; (3) The mobile Client moves from one wireless network to another and gets a new IP address A* (e.g. WiFi to 3G); (4) The mobile client informs the Home Agent that he has been assigned new IP address A*; (5) The Home Agent traps the packets sent to IP A and forwards them to IP address A* instead. It must be noted that the Mobile IP solution has a drawback. Since all traffic is forwarded via the Home Agent, the location of the Home Agent can cause additional delays since the route in which traffic traverses the Internet might not be optimal.

A limitation of WiFi networks is that even when they are sometimes free, they usually require a log in procedure. In order for the above use case to work seamlessly, access to WiFi networks should be as easy as possible, without user authentication, or by requiring authentication as seldom as possible. The Google network in Mountain View for example requires login only once every two weeks if cookies are enabled [10]. If the user is required to login every time he moves within the coverage area and tries to access the Internet, mobility will not be seamless and the calls will still be dropped. For this reason, we have omitted the use of hot spots from this use case as well, since almost all hotspots require logging in every single time. This issue is also a problem with the UMA solution.

IV. Methodology and Test Environment

The test methodology consisted of mobility tests during VoIP calls carried out using a commercial 3G network in Finland and a local WiFi link connected to the Internet.

To enable interworking across networks, we purchased a Mobile IP client from Birdstep [5]. The client is easily configured and allows prioritization of different networks to which the client can roam. For the tests, we used the Home Agent service provided also by Birdstep, which is located in Scandinavia.

The VoIP client was the default VoIP client preinstalled in the Nokia N Series and E Series devices. The moving terminal used was a Nokia N80ie. Although we would have liked to carry out the tests using high speed 3G (HSDPA), there was no commercial handheld Mobile IP client for that device (Nokia N95). Therefore our tests show mobility between ordinary 3G (WCDMA) at 384/384kbps and WiFi. The static terminal was a Nokia N95 also using the preinstalled VoIP client. Packet traces were taken from the static end (N95) and later analyzed with Wireshark software [22].

The VoIP server was provided by Gizmo VoIP [8][9]. Gizmo VoIP is a service that when registered, it provides a file that configures the Nokia VoIP client to the correct settings to use the Gizmo VoIP service. Gizmo VoIP provides free calls between Gizmo VoIP clients and cheap per minute prices to fixed and mobile numbers. Gizmo is based on open standards and the server location is in the United States. [8]

The access point was a Belkin WiFi AP (802.11b/g). To get the best possible mobility performance, we locked the transmission rate in the access point to only high modulations (24Mbps or above). In addition we configured the Mobile IP client in such a way that it attempts to roam to WiFi whenever the signal strength is high.

To determine the exact audio break in the application layer, we generated an audio stream on the mobile side and recorded the received audio on the static side. By doing so, we can evaluate what is the effect in the perceived user experience during mobility and the approximate break in the audio. Further, since VoIP clients and some codecs utilize techniques to conceal packet loss, we used three different audio sources. The first source was a continuous dial tone, the second, a number count, and the third, a text from a newspaper. Figure 3 shows the test environment and methodology.

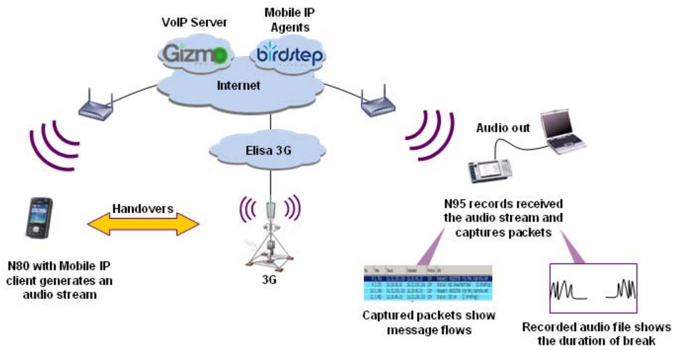

Figure 3. Mobile IP Test Environment and Methodology

A limitation of our study is obviously that, since we used commercial networks and equipment, we were unable to take packet traces from some of the main elements, such as the Home Agent. Traces from the Home Agent would clarify what is the exact behavior in the Mobile IP implementation, and in particular it would show exactly was is the data outage when changing from one network to the other. Also, the Home Agent might have mechanisms which we are unaware of, for example, it could send duplicate packets over both links to improve the mobility performance. Regardless of these limitations, the conclusions in our study still hold valid and provide an insight of the actual performance in the field.

V. Analysis and Results

The packet traces from the static end reveal that the change from one network to another disrupts the packet flow. When the mobile end remains on the same network, the signaling flow in the static end is continuous and very stable. The message flow intervals between UDP packets are roughly 25ms and 5ms. This interval continues until the mobile end begins a handover to a different network. During mobility, the message flow shows a period in which messages have an increased delay between packets. This period lasted in average 325ms when moving from WiFi to 3G, and 140ms when moving from

3G to WiFi. After this period of time, the continuous and steady message flows with intervals of 25ms and 5ms come back to normal and remain that way until intersystem mobility starts over.

Unfortunately, it is hard to know which messages were originated by each access since the Home Agent conceals the mobile end IP address to the static end. To the static end, all messages appear to originate form the same IP address. However, what these traces reveal though, is that mobility is quite fast and in the order of a few hundred milliseconds. Likewise, the increased period of uncoordinated messages and increased delay on the WiFi to 3G direction is quite natural. Since 3G has a higher wireless delay (~200ms round trip time), it will take longer to execute the required signaling with the Home Agent during mobility.

The second part of measurements results show the approximate audio break during mobility (see Figure 4 and Figure 5). The results also confirm that mobility from WiFi to 3G results in a longer break (~600-700ms) than mobility from 3G to WiFi (~100ms). What is most notable in the results is that the audio break in the application level is in fact at a very reasonable level. The audio break reveals that for the perceived end user experience, one to two words are lost when roaming to WiFi form 3G, and three to four words are lost when moving from WiFi to 3G. These results are similar to the simulations in [7]. In their algorithm for the simulation, a wireless link with 20ms delay (e.g. WiFi) would result in ~100 to 150ms disruption time depending on the handoff mechanism. Likewise, a wireless link with of 200 ms (e.g. 3G) would result in 600-800ms. This algorithm is remarkably close to our measurements. On the other hand, our results differ from the seamless mobility in the measurements provided by [11]. Likewise, such measurements did not use actual VoIP audio. The measurements in [11] also showed some tests with breaks of 2.5 seconds when radio resources were not available and a cell state change in the cellular system was triggered. In our measurements, the cell state change does not play a role in the audio break, since the handset connects and sends packets over the 3G wireless link before it attempts to switch from WiFi. Therefore, by the time the intersystem handover is executed, the packet data connection with the 3G service is already active and in the CELL_DCH state.

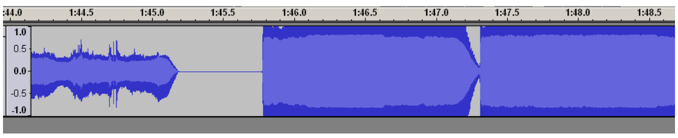

Figure 4. Mobility Test Example 1(Dial Tone) (1) WiFi to 3G & (2) 3G to WiFi

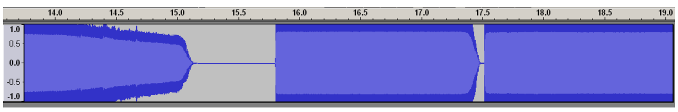

Figure 5. Mobility Test Example 2 (Dial Tone) (1) WiFi to 3G & (2) 3G to WiFi

Even though the audio break is considerably higher than typical GSM inter-BSC handovers (120-220ms) [1], they are still similar to those encountered in WiFi deployments when WPA encryption is used (700ms-1000ms). We assume that if full scale enterprise VoIP over WiFi services using WPA encryption have been deployed, and in which employees are able to get used to such breaks during mobility, under a right business model, end users could cope with the breaks resulting from WiFi to 3G mobility as well. Table 1 summarizes our test results.

Table 1. Mobile IP Tests Summary

Handover	Audio Break	Perceived End User Experience	Abnormal Message Flow
WiFi-to-3G	~600-700ms	Several words lost	325ms
3G-to-WiFi	~100ms	1-2 words lost	150ms

Furthermore, if we model evolved 3G wireless radio links (HSDPA, HSUPA, and HSPA+) with the algorithm in [7], we notice that the performance can improve considerably (see Table 2). Likewise, these wireless access technologies can provide much better VoIP quality than ordinary 3G due to the lower round trip time. We assume the algorithm for the estimations to be representative due to its close results to our measurements.

Table 2. Mobile IP Audio Break Estimations based on [7] Algorithm for Future 3GPP Releases

Handover	Wireless Link Delay	Audio Break
WiFi-to-HSDPA	85ms (HSDPA)	~275-450ms
WiFi-to-HSUPA	65ms (HSUPA)	~225-350ms
WiFi-to-HSPA+	45ms (HSPA+)	~175-275ms

In outdoor scenarios, it is important to emphasize that if the VoIP service and access to the metropolitan wireless mesh network is not considerably cheaper than cellular, end users are likely to prefer traditional cellular voice services due to its better quality. We also believe that VoIP in wireless mesh networks is not a replacement for cellular connectivity, especially due to the lack of wireless mesh coverage [2][20] Instead, VoIP is an alternative solution that by using Mobile IP, it can be available in most places where users are likely to start a conversation (home, office, main streets) via one of the different wireless access networks. Likewise, VoIP quality over cellular networks is still far from optimal. This is mostly due to the large wireless link delay when compared with WiFi. WiFi deployments usually have round trip times between 5 and 25ms depending on the signal conditions [2]. Contrastingly, cellular networks have roughly 200ms for Release 99 (WCDMA), 85ms for Release 5 (HSDPA) and 65ms for Release 6 (HSUPA). The wireless link delay is not the only source of delay, in addition encoding / processing delay accounts for roughly 200ms and the jitter buffer implementation for more than a 100ms. While these client dependent delays are lower when using laptops, the main use case for VoIP services is with handsets, not laptops.

This means that for example, 3G cellular coverage can provide mobility and avoid dropping calls whenever WiFi coverage is not available. However, the quality of VoIP over current cellular network is considerably lower than over WiFi. Therefore, using WiFi for VoIP should be preferred from VoIP over cellular due to its lower delay. As 3G networks are upgraded to later releases (HSDPA, HSUPA, HSPA+), the performance gap will be reduced and quality for VoIP in 3G should no longer be an issue.

For the above reasons, the main motivation for using VoIP instead of traditional voice services is still mainly price oriented. Therefore, the price must be considerably lower than ordinary cellular voice calls (e.g. Skype or Gizmo) in order to encourage users to use this kind of solutions over ordinary cellular voice.

Another benefit of using Mobile IP is that the user's VoIP identity is always reachable. Also, some other scenarios exist in which Mobile IP brings further improvements. For example, in Finland public transportation buses provide in-bus WiFi connectivity and use FLASH-OFDM technology as backhaul. FLASH-OFDM is a particular wireless technology with very low delay (around 30-50ms) and can carry VoIP services with good performance. In cases like this, users can benefit of the additional WiFi coverage also on mobility scenarios.

VI. CONCLUSIONS

Multiple measurements were carried out to evaluate the performance and feasibility of using Mobile IP as an enabling technology for VoIP services in wireless mesh networks. The measurements show that in overall VoIP continuity is achieved at a reasonable level with Mobile IP. However, the application audio break is not seamless in both directions. In addition, the VoIP quality over cellular is still far from optimal. However, if the price for the service and wireless access is considerably cheaper than cellular voice, it will be possible to encourage users to use the service despite the performance limitations. As 3G networks are upgraded to later releases (HSDPA, HSUPA, HSPA+), the performance gap will be reduced and quality for VoIP in 3G should no longer be an issue. In regards to home scenarios, VoIP over WiFi already works, but Mobile IP will improve it by enabling VoIP continuity from the home environment to outdoor networks such as wireless mesh or cellular.

In what regards to client installation and provisioning, the easy setup, installation and configuration of services such as Birdstep Mobile IP and Gizmo VoIP, make Mobile IP an interesting possibility to improve performance in metropolitan wireless mesh networks.

Future work, includes a performance evaluation with own network elements, as well as packet traces from the Home Agent to uncover the missing pieces from the research in this paper. In addition, since 3G networks are unable to provide high quality VoIP, we will extend the measurements for mobility between HSDPA (or HSUPA) and WiFi once a Mobile IP client for a handset device with VoIP is available and characterize the performance improvement.

REFERENCES

[1] 3rd generation Partnership Project (3GPP), "Radio Subsystem Synchronization", 3GPP Technical Specification, TS 05.10 V8.12.0, August 2003.

[2] A. Arjona and S. Takala, "The Google Muni WiFi Network – Can It Compete with Celular Voice?", In Proc. of IEEE Advanced International Communications Conference (AICT'07), Morne Mauritius, May 13-19, 2007.

[3] A. Arjona and H. Verkalaso, "Unlicensed Mobile Access (UMA) handover and Packet Data Performance Analysis" In Proc. of IEEE International Conference on Digital Telecommunications (ICDT'07), Silicon Valley USA, July 1-5, 2007.

[4] BelAir Networks, http://www.belairnetworks.com

[5] Birdstep Mobile IP, http://www.birdstep.com

[6] H. Fathi, S. Chakraborty and R. Prasad, "Mobility Management for VoIP: Evaluation of Mobile IP-based Protocols", In Proc. of IEEE International Conference on Communications (ICC'05), May 16-20, 2005.

[7] H. Fathi, R. Prasad, and S. Chakraborty, "Mobility Management for VoIP in 3G Systems: Evaluation of Low Latency Handoff Schemes", IEEE Wireless Communications, Vol. 12, Issue 2, pp. 96-104, April 2005.

[8] Gizmo Project, http://www.gizmoproject.com

[9] Gizmo VoIP, http://www.gizmovoip.com

[10] Google WiFi, http://wifi.google.com

[11] S. Grech, H. Haverinen, and V. Devaparapalli, "Towards Service Continuity in Emerging Heterogeneous Mobile Networks", In Proc. of IEEE Vehicular Technology Conference – Spring (VTC'06), Melbourne Australia, May 7-10, 2006.

[12] Helsinki University of Technology: Dynamics Mobile IPv4 Implementation from Helsinki University of Technology, http://dynamics.sourceforge.net

[13] Helsinki University of Technology: MIPL – Mobile IP for Linux. http://www.mobile-ipv6.org

[14] J. Jung, R. Mudumbai, D. Montgomery and H. Kahng, "Performance Evaluation of Two Layered Mobility Management using Mobile IP and Session Initiation Protocol", IEEE Global Communications Conference (GLOBECOM'03), Dec 1-5, 2003.

[15] T. Kwong, M. Gerla, S. Das, and S. Das, "Mobility Management for VoIP Service: Mobile IP vs. SIP", IEEE Wireless Communications, Vol. 9, Issue 5, pp. 66-75, October 2002.

[16] Meraki, http://www.meraki.net

[17] SkyPilot, http://www.skypilot.com

[18] Strix Systems, http://www.strixsystems.com

[19] C. Perkins, "IP Mobility Support for IPv4", IETF RFC 3344, August 2002.

[20] M. Thelander, "Google Wireless – Through Rose Colored Goggles", Signals Ahead, Vol. 4, No. 7, March 27, 2007.

[21] Tropos Networks, http://www.tropos.com

[22] Wireshark Protocol Analyzer, http://www.wireshark.org

[23] S. Zeadally, F. Siddiqui, N. DeepakMavatoor, and P. Randhawa, "SIP and Mobile IP Integration to Support Seamless Mobility", In Proc. of IEEE Personal Indoor and Mobile Radio Communications (PIMRC'06), September 5-8, 2004.