Cellular to WiFi Handoff

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Abstract

For the purposes of learning and understanding the Fixed Mobile Convergence (FMC) and its infrastructure, this paper presents and analyzes the Hand-Off (HO) procedure between WLAN and Cellular networks. A Mobile Node (MN) needs to support both technologies before a hand-off between the two networks may happen, such mobile system is referred to be a Dual-Mode (DM) device. When a DM mobile phone enters a WLAN’s network and the device detects a strong power signal from the WLAN, it will initiate a vertical handoff (VHO) request if a preset threshold has been reached. A soft handoff can be achieved through a Hand-Off Trigger Node (HTN) scheme, where the HTN may be either tightly or loosely couple. Furthermore, the Unlicensed Mobile Access (UMA) will be presented, which is used by the loosely coupled HTN technique where it delivers IP Multimedia Subsystem/Session Initiation Protocol (IMS/SIP) type applications to the mobile device.

Introduction

As the world advances towards a more mobile and wireless future, the expectations of better services and products that are offered grow simultaneously. The mobile telephony has grown tremendously in the amount of users throughout the past decade, and now a new generation of this communication system is approaching, where people want to be able to use their hand-held cellular phones wherever they go and with a better performance. This idea cannot be supported by the cellular system as a stand-alone, therefore the combination and help of the WiFi technology is needed. The Wireless Local Area Network (WLAN) will complement the emerging mobile technology where a user can roam between cellular and WLAN accessible areas flawlessly. This performance has been improved significantly during the past 3 to 4 years, where a voice handoff was previously was not possible, where the mobile phone could not work the cellular network’s spectrum with the WLAN’s spectrum simultaneously. Now, with this issue being resolved, there is the issue of the quality of handoff for voice calls remaining, where handoff time is a very critical aspect. This and other issues may lead to a handoff failure. The handoff failure may never be resolved completely, but it may be reduced significantly. The goal is to make the following scenario work stable and consistent:

![Figure 1: Vertical Handoff](image-url)
In order for a vertical handoff to take place there are several signaling and communication messages needed. The specific procedure that a mobile goes through in the case of a downward vertical handoff is as follows:

Similar to the down-link of the vertical handoff, the up-link follows several communication steps in order to successfully create a handoff. These communication steps are as follows:
Problem and Approach

The specific problem of intercommunicating and roaming between the WLAN and Cellular networks is the handoff. Handoff is the switch between one network to another. In FMC handover in refers to roaming from a Macro network, which is the cellular network, into a WLAN network. Handover out is the opposite, which represents the roaming from WLAN into a Macro network. The performance of the handoff is dependant on the speed of the traveling mobile device, but more importantly of the technique and structure how the handoff between the networks takes place, where the handover time is critical and acceptable if $\leq 5\text{sec}$. This leads us to the options available to provide a stable roaming performance.

Handoff Trigger Node (HTN) is a detector and data link layer triggering technique that needs to be installed on the mobile set. HTN provides the Mobile Node (MN) with advanced search and detection techniques that makes roaming in and out of WiFi areas a much easier manageable and acceptable procedure. These nodes may be predefined on the mobile node (MN) or the device may be informed by the cellular network when entering an area where there is a WLAN accessible, in order make the detection of a WLAN even easier. These areas are going to be limited in the number, because cellular provider will not always know about how many WLAN’s there are and where, and if new ones have been added in a specific area, and it would mostly advertise WLAN networks which are operated by the cellular provider itself. Anyhow, there are two specific types of Handoff Trigger Nodes (HTN’s) available:

1. Tight-Coupling:
   In tight-coupling the WLAN is integrated into the Cellular provider’s core network and an interworking gateway, which translates the incoming packets, makes this adaptation possible. Tight-coupling benefits from low loss of packet rate and good handoff delay, since it uses native cellular mobility management protocols. Therefore, tight-coupling is the better performing type of HTN, but it’s much more costly than loose-coupling. The use of tight-coupling architecture also takes away from other internet and WLAN providers, where they cannot come into the scenario.

2. Loose-Coupling:
   In a loosely couple architecture, the mobile node is connected to the cellular network through an external IP network, where the packets are redirected through the internet to the cellular provider’s network. The architecture is less proprietary, since there is no expensive wired connection from the WLAN to the service provider’s core network. On the other hand, this approach suffers from a harder to achieve handoff in real-time cases, such as a voice connection, because the Session Initiation Protocol (SIP) and other connection requirements and signaling produce a longer delay in handoff. Therefore, this type of HTN coupling produces a lower performance due to a higher Handoff failures. This approach also enables other internet, service and WLAN providers to come into the picture, where they may offer WLAN access pints (AP) and charge as they wish. This will allow a much larger number of WLAN AP’s to come into picture and be used, since now more providers may benefit from this technology.
Furthermore, HTN enabled mobile devices are not necessarily a lot more energy consuming than the ones that are not. Un-enabled devices need higher layer signaling functions and when inside a WLAN’s coverage, they need to constantly search the area for a cellular Base Station (BS). Using HTN, transition areas between WLAN’s and cellular networks are very site specific, therefore having prior knowledge about these areas, can significantly reduce the power usage without sacrificing performance of handoff and dropped calls. Therefore, the HTN provides better communication skills between the mobile node (MN), which is the mobile device, and the surrounding networks. Although, the HTN will not initiate a handoff until the MN has reached a site-specific received signal strength indication (RSSI) threshold.

Basically HTN is an enhancement to the MN, where it empowers the MN to easily grab the Mobile Station’s Multimedia Access Control’s (MS MAC) address and start communicating with the Access Point (AP) whenever needed. The use of HTN also allows the MN to scan the AP’s coverage area, and depending on its location, the MN may turn off it’s cellular radio to preserve power. The same holds when the user is in a macro network. The MN may easily switch between accessible AP’s where the device is able to scan various channels of interest. The following graph shows the two scenarios where an MN is Handoff Trigger Node (HTN) enabled in one case and not in another case:
Although that HTN makes continuous roaming without disconnecting and reconnecting to the service provider’s core network more manageable, it is still to be improved in the case of a handover out, a transition from WiFi into a cellular network, where the probability of dropped calls is much higher compared to the probability of dropped calls occurring during a handover in. This is due to the longer time that it takes to initiate a communication link with the core network and upon its approval initiating a handoff. During a handover out, handoff time is very critical where the received signal power may decline sharply as the the distance away from the AP is increased slightly. The following graphs show a comparison between a handover in and handover out:

![Fig. 6: WiFi to GSM transition time compared with GSM to WiFi transition time](image)

Analyzing the two graphs above, it is clear to see that the handover in takes only a few milliseconds to complete after an initiation protocol has been started. On the other hand, it is easily recognizable that the handover out, where there is a transition from WLAN into a cellular network, is the bigger constraint of the handoff procedure, where it takes more than 5 seconds to complete a handoff after an initiation has been triggered.

Once a handover in has been initiated, the SIP will use the IP to reach the Public Switched Telephony Network (PSTN). This is achieved using the Unlicensed Mobile Access (UMA), which has now been renamed to Generic Access Network (GAN). UMA allows the cellular service provider to deliver data, voice and other IMS/SIP type applications to mobile phones. It is the technology that makes the Fixed Mobile Convergence (FMC) possible, and on which the loosely coupled HTN is completely dependent. On the other side, the UMA operates independently from cellular providers, it is managed by a separate network controller, namely as Unlicensed Mobile Access Network Controller (UNC).

The GAN’s communication protocols are placed above the transport layer (TCP). The UMA is also able to update the cellular provider with the user’s current location and performance. Since it is able to communicate with the cellular service provider’s core network, it is going to arrange a smooth vertical handoff back into the outdoor cellular system in a way that should be unnoticed by the user. Generic Access Networks (GAN’s) allow providers to extend their coverage in a cheap way using the 802.11 AP’s, where there is no need for expensive base stations to be set up in unnecessary locations. It will also relieve congestion from the GSM or UMTS spectrum by placing calls on the internet and freeing up channels for user in the outdoor using cellular base stations, this will further decrease the probability of new calls being blocked. Also, this way service providers can create more capacity and better coverage in denser
populated areas. The cheaper rates using 802.11 with a high quality of service can even be used to replace the traditional land line at home. GAN is the only current technology available that combines GSM and 802.11 into a service that uses a single number, a single handset, single set of services and a single phone directory for all calls. Currently, the only disadvantage of this technology is the costly dual mode (DM) mobile device (MD) that is performance wise and battery life wise limited. The UMA is placed into the WiFi/Cellular network as follows:

![Cellular and Internet Telephony using a Mobile Device](image)

**Fig. 7: Cellular and Internet Telephony using a Mobile Device**

The only current vulnerable aspect of UMA/GAN is the security. Where this network does not require security to operate, it can coexist with various security applications, such as firewall, Virtual Private Networks (VPN’s), Denial of Service DoS attack prevention and Wired Equivalent Protocol (WEP).
Results

Handoff Trigger Node (HTN) has now provided us with a technique, which produces reasonable results, that makes roaming within cellular and WiFi networks a more seamless process. Now understanding the usage statistics of a WLAN, the Handoff probabilities of one Base Station (BS) to another will be compared to the one of BS to WLAN network. For this purpose, considering an incoming call rate of $\lambda = 0.1 \text{ sec}^{-1}$, an average call holding time of $1/\mu = 100 \text{ sec}$ and a cell radius of $r = 1 \text{ km}$ is considered. The probability of handoff from one base station to another in a cellular network is obtained using the following equation:

$$P_h = \frac{\eta}{\eta + \mu}$$

where $\eta$ is the cell dwell time, which is the amount of time a user spends in a cell on the average, and $\mu$ is the average call holding time. Where $\eta$ is obtained by calculating the following formula:

$$\eta = \frac{v \times L}{\pi \times s}$$

where $v$ is the velocity of the moving mobile in kilometers per second, $L$ is the perimeter of the cell, where in an hexagonal cell it equals to $6 \times R$ and $R$ is the radius and it must in kilometers. Also, $s$ is the area of the cell of interest, which is easily computed by $s = \pi \times R^2$. These calculations will yield the following statistics:

Note: All of the following plots have been created using MatLab.

![Probability of Handoff between BSs vs Speed of Mobile Node](image.png)

**Fig. 8: Prob. of Handoff from one BS to another**

Now to see the probability of handoff into a WLAN using the same amount of call holding time that was placed on the previous analysis, the following probability of handoff into a WLAN is obtained, assuming that WLAN’s are widely deployed in socializing areas, such as coffee shops, bookstores and others. It’s probability of blocking is obtained using the Erlang-B Formula:

$$P_B = \frac{\rho^N / N!}{\sum_{k=0}^{N} A^k / k!}$$
where $N$ is number of available channels and $\rho$ is the load of the network. These probabilities are illustrated in the following plots:

![Probability of Handoff from cellular to WiFi vs. Speed of Mobile](image1.png)

![Probability of Blocking during a Handover In vs. Number of available Channels](image2.png)

**Fig. 9:** Prob. of Handoff from a BS into a WLAN and its blocking probability

To further examine the behavior of the handoff, the probability of blocking during a handover out from a WLAN into a cellular network is considered. Knowing that on average the amount of time it takes to set up a handoff into a cellular network is much greater than setting up a handoff into a WLAN, it is expected that the probability of handoff failure ($P_{Hf}$) is great and should have a tremendous amount of influence on the roaming behavior and statistics. The following plots will provide a better image in understanding this behavior, where in the left plot we assume that the mobile is moving at a walking speed and in the right plot the mobile takes different velocities:

![Probability of Blocking during a Handover Out vs. Number of available Channels](image3.png)

![Prob. of Handoff failure at Handover Out vs. Speed of Mobile](image4.png)

**Fig. 10:** $P_B$ in a Handover Out and $P_{Hf}$ from a WLAN to a BS
Conclusion

Fixed Mobile Convergence (FMC) will be the next generation of mobile communications, where fixed and mobile telephony will be combined into one. This paper presented and analyzed the Hand-Off (HO) procedure between WLAN and Cellular networks. A Mobile Node (MN) needs to support both technologies before a hand-off between the two networks may occur. When a DM mobile phone enters a WLAN’s network and the device detects a strong power signal from the WLAN, it should initiate a vertical handoff (VHO) request if a preset threshold has been reached. A soft handoff was achieved through a Hand-Off Trigger Node (HTN) scheme, where the HTN may be either tightly or loosely coupled. Furthermore, the Unlicensed Mobile Access (UMA) was presented, which is used by the loosely coupled HTN technique where it delivers IP Multimedia Subsystem/Session Initiation Protocol (IMS/SIP) type applications to the mobile device. It has determined that more emphasis should be given towards the handoff procedure when leaving a WLAN and trying to access a cellular network. Conclusively, roaming between WLAN’s and BS’s is made more seamless and operative by the HTN technology, where the results present a positive support for this technique.

References


