# Speed-Based Mobility Management for Heterogeneous Wireless Networks Interworking

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## Abstract

*A heterogeneous wireless network is constructed by a variety of wireless networks. More and more researches try to achieve seamless handoff between WWAN and WLAN in accordance with all layers. It is anticipated that the future wireless mobile Internet will be a pluralistic wireless environment. Majority of traditional location management schemes are based on paging mobile terminal within each domain area. This paper proposes a speed-based mobility management scheme to minimize the paging overhead cost and the resource reservation. Our proposed scheme consists of three main approaches. First, the mobile terminal location update is based on the movement speed, and this information will be transmitted to the system for dynamic management. Second, the required bandwidth of an application is dependent on the selection of the most suitable wireless network dynamically. Lastly, the classification of applications is applied to avoid handoff failures. The simulation results show about 40% reduction in signaling cost and significant paging delay improvement.*

## 1. Introduction

It is anticipated that the future wireless mobile Internet will be a pluralistic wireless environment [4, 5]. A heterogeneous wireless environment is made up of wireless networks with different properties, such as 3G telecommunication (WWAN)[1], WLAN[2], WiMax[3], Bluetooth, and the like. Among these networks, 3G telecommunication has driven the Internet to support a mobile terminal, and this implies the integration of IP and wireless technologies. The core of 3G network is purely packet switched. To encourage this wireless environment, mobility management plays a critical role.

In general, the mobility management in wireless networks consists of two interoperable components: the location manager and the handoff manager. The location manager performs two complementary operations, i.e., Location Update and Paging, and its main purpose is to confirm the mobile terminal's current position. Location Update (LU) is activated by a mobile terminal (MT), whereas Paging is initiated by a network system. Handoff may be restricted within a system (such as within WWAN) or between heterogeneous systems (such as between WWAN and WLAN).

In order to deliver packets correctly to a moving user, the system must have a way to page the mobile terminal, or the mobile terminal has to update its location information voluntarily. There have been a number of researches done on location management. The interaction between location update and paging in order to decrease the signaling transfer for a homogenous wireless network has been addressed in the past [6, 7, 8].

Large geographical areas are covered by more than one radio resource. The WWAN and WLAN (may also be WiMax) are expected to co-exist at the same time for the mobile user. Each wireless network has its own characteristics. It will form a hierarchical wireless access network. Generally speaking, the WWAN service coverage is the largest, and has the highest mobility support. On the other hand, WLAN has a relatively smaller coverage and lower mobility support, but it has higher data transfer rate and cheaper cost.

The location management schemes for a heterogeneous wireless network usually suffer because of unnecessary signaling transfer and unsuitable handoff timing. Mobile users' demand for wireless radio resource depends on several factors, such as movement behavior, application types, or fee consideration. However, these factors are often changed during the usage period. The system must therefore make adjustments dynamically.

This paper discusses the mobility management in a heterogeneous wireless network system with the aim to decrease overhead costs. We try to interoperate location management and handoff management. In the past, the two are regarded as independent tasks. The system obtains the mobile user's speed by detecting LU frequency, and derives the application type-information by PDP context. The PDP context is a data structure to describe the users' session information present on a 3G core network. The information can be used for designing the paging strategy, detecting the handoff trigger, and deciding the handoff timing dynamically.

The remaining section of this paper is organized as follows. Section 2 presents the background related to the research. Section 3 describes in detail the proposed heterogeneous wireless network mobility management. Section 4 shows the simulation and the corresponding results. Section 5 presents the conclusions of the study. Finally, session 6 is references.

## 2. Background

### 2.1WWAN/WLAN Interworking

Many dual-mode or multi-mode wireless interface terminal devices are allowed to access heterogeneous wireless networks. In turn, the need for handoff between a WWAN, such as 3G networks or public WLAN, and WiMax is also increasing.

To achieve seamless handoff between WWAN and WLAN, the system and terminal devices must face all the intra and interlayer problems [9]. For example, the physical and link layers should have multi-mode interfaces and a support handoff/switch mechanism. In a network layer, the wireless system must perform packet re-routing actively in order to deliver packets correctly to the moving users during access network shifting (it implies an IP address change). Mobile IP [13], cellular IP, and Hawaii [14] are proposed to solve the problem of terminal mobility by redirecting packets for the mobile node to its current location. In the transport layer, Stream Control Transmission Protocol (SCTP) [15] was recently proposed by the Internet Engineering Task Force. In the application layer, the Session Initiation Protocol (SIP) [16] is getting widely accepted as an application layer signaling the protocol for Internet multimedia and telephony services that can be used in the wireless Internet. However, SIP focuses on enabling packet rerouting to the new point of attachment, and the aspects of relocation of application-specific functionality are not discussed when handoff occurs. Some researches focused on the application layer about context transfer to achieve seamless handoff across heterogeneous wireless network. In [17], a framework called Application Context Transfer is proposed to solve the problem of network bandwidth differences between two systems.

### 2.2Location Management

Location management is an important process that enables the network to maintain the latest location information. Majority of wireless systems maintain location information using the LU and paging mechanisms. LU is a process in which MT informs its up-to-date location information voluntarily. Paging is another process for a network to track an MT's current location. However, more paging by system implies less location update by MTs, and vice visa. Many researches focused on the balance between the two in order to save scarce wireless resources. A network can group cells or base stations into Location Areas (within a circuit switch domain) or Routing Areas (within a packet switch domain). When an MT stays at the same LA/RA, it is not necessary to transfer the signaling to each other between the device and the system. In the other words, there is no LU by MT and paging by the system during this period of time. Based on this concept, many LU and paging strategies are developed. Many LU strategies have been proposed, including time-based [6], distance-based [6], and profile-based approaches [7]. On the other hand several paging schemes have been proposed, including Blanket paging, Shortest-Distance-First and Sequential Paging [8].

### 2.3Handoff Management

Handoff management maintains a connection for the MT when the point of attachment changes [19]. There are two types of handoff in a heterogeneous wireless network. An intrasystem handoff (or horizontal handoff) refers to the MT change from the point of attachment which belongs to the same network. Meanwhile, an intersystem handoff (or vertical handoff) refers to the MT change from the point of attachment between different networks. Intrasystem handoffs are always triggered when the signal strength is lower than the predefined threshold of a base station. An intersystem handoff may be triggered when either the MT moves out of the serving area, or the capability of a certain network is unsuited for the MT. Also, distributing the load of one network to another can optimize the performance as a whole.

The intersystem handoff is more complicated than the intrasystem handoff. The MT demand and characteristic should be realized by both networks. Our proposed scheme is aimed at intersystem mobility management. We grasp the MT's speed and application information which offer the system more information in order to select the most suitable wireless networks.

## 3. Speed-based Mobility Management

Location management and handoff management are two independent tasks in earlier wireless network systems. Each wireless network develops its own specification. Handoff triggers always occur based on system boundary, which is measured by the radio signal strength (RSS). In a heterogeneous wireless network, this concept is no longer suitable. More handoff trigger events should be considered, including the user's speed and the application's bandwidth demand. When the MT moves from WWAN to WLAN, it may get more network bandwidth with a lower cost. In the reverse direction, when the MT is operated in high speed, a handoff from WLAN to WWAN is needed. These handoff triggers are different from those in a traditional environment. In addition, WWAN is usually always on, while the handoff cannot be triggered by the RSS of the current system, like the horizontal handoff.

To date, more and more mature technologies are emerging, and each system has its own unique characteristics that cannot be replaced. An interoperable model is expected to bring more facilities for every MT. Then in order to decrease unnecessary signaling transfer and to detect the best handoff triggering event, we proposed to address this problem by considering two parameters: users' movement speed and application types.

### 3.1 Users' Movement Speed

Each wireless network system supports its service range at a certain speed. Hence, movement speed is an important concern in designing dynamic location management and handoff management schemes. A suitable strategy will eliminate unnecessary signaling transfer, and will select a good timing for handoff.

Among various LU strategies, the time-based and distance-based strategies are the two most commonly used strategies in exiting wireless networks. Considering the time-based strategy, the MT performs LU periodically at a predefined constant interval. The system measures the distance between the current cell and the last LU cell, then calculates the speed of the MT. As to the distance-based LU, the system sets a timer and calculates the speed. In addition to speed, the system will also get the MT's direction of advancing. This operation is expressed in Figure 1.

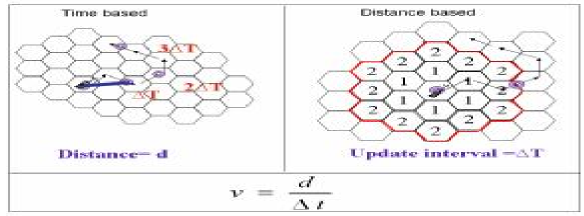


**Figure 1: Calculate movement speed**

Based on speed and direction information, we will begin to design a new paging scheme. Under most movement behaviors, speed is related to the turn-angle. When one is driving at a high speed, it is difficult to manage the vehicle when making a turn due to the tendency of inertia to be unstable. Hence, all roads must have a regulated speed limit for all vehicles. On the other hand, the movement behavior of a mobile user in low speed is similar to a random walk. Based on this law of nature, paging scheme A is designed. When the MT is at a low speed, the paging area (fan shaped) is the biggest. The random walk direction of advancing is difficult to predict. However, to the MT who is at a higher speed, the direction is easier to predict. As a result, the paging area will be smaller. Even paging scheme A will decrease the paging cost in some case, but it is not efficient at low mobility. To further improve the performance, paging scheme B is thus proposed.

The idea of scheme B is depicted in Figure 2. First, the point of entry of a mobile terminal is considered as the center of a circle, and a semi-circle-shaped paging area is formed. Second, the paging area is partitioned into several sub-paging areas, as shown in Figure 2. The hot zone is bounded by an angle θ, and θ is generated by two formulas:

$$x = \frac{v}{G} \tag{1}$$

$$\theta = 2 \tan^{-1}\left(\lim_{\Delta x \to 0} \frac{\Delta \ln x}{\Delta x}\right) \tag{2}$$

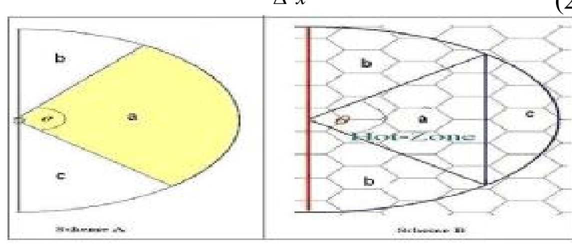


**Figure 2: Paging scheme A and scheme B**

These formulas determine the angle θ from the change of speed (v). Argument G, as in (1), is an environmental variable. Road design principles and the driving/walking behavior affect the value of G. It is a parameter which is tuned by the tele-operators rely on vary area for the best θ.

The hot zone is an isolated triangle bounded by θ. MT may stay in this area with a high probability. The right and left sides of the hot zone are called area-b, and the part in front is called area-c. Since a different speed affects the probability of a mobile user to stay in different areas, our policy is based on the paging sequence order for sub-paging areas. If the speed is high, we adopt the Depth First paging order. This paging order involves paging area -a, c, and b in sequence. If the speed is medium, the paging order is area -a, then b and c at the same time; this paging order is called Depth-Bread. If the speed is low, we adopt the Bread First paging order. The Bread First paging order is a, b, and c in sequence.

### 3.2 Application Types

Network bandwidth demands vary according to different types of application. On the other hand, each wireless network has its own range of bandwidth support. In a homogeneous wireless environment, application difference is not considered in mobility management. However, application type plays an important role in a heterogeneous environment. The bandwidth difference between WWAN and WLAN is significant. Without considering the application type in mobility management, unnecessary handoff, signaling overhead, and resource reservation are all possible outcomes. The application-type information resides in the packet data protocol (PDP). The PDP context is a data structure which describes users' session information presented to a 3G core network. This session management consists of PDP context activation, deactivation, and modification procedures. When an MT wants to use 3G, it must first attach to the network and then activate a PDP context. Our proposed scheme follows these procedures. The application information is obtained through the PDP context, and it provides the system for the paging decisions.

The UMTS traffic is divided into four classes. In our scheme, we simplified and re-defined the classes of both managed systems. Considering the application bandwidth demands, two application types are defined. If the bandwidth demand is under the capability of UMTS, we call it a low-class application. If the bandwidth demand is higher than UMTS' capability, we call it a high-class application.

### 3.1 Paging Scheme Design

At the time the MT performs LU and activates the PDP context, both speed and application-type information are available from the system. Then the system will start the paging process. First, the system will construct the dynamic paging area. Then a paging sequence order is determined based on the speed and application type. The detail of this process is illustrated in the following.

```
Construct:
    1: Get MT Location Update coordinate A:(X,Y)
    2: Look up the last time LU timing and cell coordinate
    3: Calculate MT's speed (V) and direction
    4: Regard the enter point as the center and according
    direction to construct a paging area (Like a semicircle)
Paging Area Dynamic Partition:
    While V=fast (>>WLAN e.g. Freeway)
    WWAN Paging Area Partition (PAP) by Depth First
        and WLAN not maintain
    While V=medium (e.g. City)
      if bandwidth demand is high
        WLAN PAP by Depth-Bread
      else
        Both PAP by Depth-Bread
    While V=Low (e.g. Walk)
     if bandwidth demand is high
        WLAN PAP by Bread First
     else
        Both PAP by Bread First
```

### 3.4Performance Model

The paging cost is a function of numbers of cells and signaling. It can be expressed as below:

$$Cost = N * C_u \quad ,\text{Where} \quad \begin{matrix} \textbf{N: numbers of cell} \\ \mathbf{C_u}\textbf{: cost per signaling} \end{matrix}$$

This paper proposed a scheme to improve the static scheme caused too reduce number of signaling in heterogeneous wireless networks. The static blanket paging is used for comparison. The paging area partitioned into three sub-paging areas: area "a" (i.e. Hot Zone), area "b", and area "c". The expected cost is calculated, and compared with the simulation results.

$C_{C\_CA}$ and $C_{P\_PA}$ denote the cost of constructing and partitioning dynamic paging area. The dynamic paging cost is calculated as the following equation:

$$C_{P\_D} = C_{C\_PA} + C_{P\_PA} + C_u(P_h N_{HZ} + P_b \times N_b + P_c \times N_c)$$

, where $P_x$ is the probability of MT at x area

Whereas the paging cost of static scheme can be expressed as the equation below:

$$C_{P\_S} = C_{P\_PA} + \frac{2(\gamma + 1)}{3} C_u \times N$$

Considering the heterogeneous system with WWAN and WLAN, one WWAN base station can cover γ WLAN access points. Assume α and β denote the switches of speed and application types, the paging cost would be re-calculated as an equation:

$$C_{P\_D} = C_{C\_PA} + C_{P\_PA} + \alpha \times C_u (N_{HZ} P_h + P_b \times N_b + P_c \times N_c) + \beta\gamma (N_{HZ} P_h + P_b \times N_b + P_c \times N_c)$$

Then, the static paging is re-calculated as the following equation:

$$C_{P\_S} = C_{P\_PA} + \frac{1}{3}\left(\frac{1}{3} N \times C_u + (\frac{1}{3} N \times C_u) \times 2 + (\frac{1}{3} N \times C_u) \times 3\right) = C_{P\_PA} + \frac{2}{3} N \times C_u$$

The static broadcast paging generates more signaling then the dynamic schemes. However, the sub-paging area partitioning creates additional delay. Assume $P_x$ denotes, the probability of MT at x area, the delay of dynamic scheme is calculates as following equation:

$$D_{P\_D} = P_h D_u + P_b \times 2 D_u + P_c \times 3D_u$$

, where $D_u$ is one unit of paging delay

The delay of static paging scheme can be expressed as:

$$D_{P\_S} = D_u + (\frac{1}{3})2D_u + (\frac{1}{3})3D_u$$

# 4. Evaluation

## 4.1 User's Mobility Behavior

Obtaining the real movement patterns is not a trivial task; thus, a common approach is to use simulated mobility models [9]. Based on such models, the movement patterns related to network characteristics can be provided. The most used model in ad hoc networks is the Random Way Point (RWP) model [10].

In this simulation, we adopted two models for MT movement behavior. One is the Random Way Point Mobility Model [11], and the other is the Profile Base Mobility Model. Both models were implemented in the simulation tools QualNet [12].

In the RWP mobility model, each node randomly selects a destination point. It moves in the direction of the destination in a speed uniformly chosen between [Vmin, Vmax]. After it reaches its destination, the node stays there for a predefined pause time tp, and then starts moving again according to the same rule. Meanwhile, the profile base mobility model provides the patterns that are contained in a time-ordered trace file of node positions. Each line of the trace file includes the node id, time, and destination coordinate.

The configuration parameters, which are listed in Table 1, describe the environment of our speed-based mobility management experiment. We tested each scheme with different speeds and application types.

**Table 1: Simulation parameters and default**

| Parameter Name | Value | EXP. |
|---|---|---|
| Each WWAN Cell Coverage Distance | 1000 m | |
| Each Cell Cover Numbers of WLAN AP | 6 | |
| Time-based Threshold | 30 min | |
| Paging Area Radius | 20 KM | |
| Speed of MT | 0.5-30 m/s | * |
| Application Classfication | H/L | * |

## 4.2 Simulation Results and Discussion

The average paging cost (i.e., number of signaling) with different speeds in heterogeneous architecture is shown in Figure 3. We compared the dynamic scheme and traditional static scheme by paging cost in a heterogeneous environment (it means WWAN and WLAN). This experiment adopted dynamic paging scheme A with different degrees of enhancement, and included the pure dynamic scheme, dynamic scheme with speed filter, and dynamic scheme with speed and application filter. Unfortunately, the results show that the paging cost at a low speed is not efficient. The reason for this is that paging scheme A leads to a relatively large paging area at a low speed. As to medium speed, the paging cost slightly increased since the MT may be out of the hot zone.

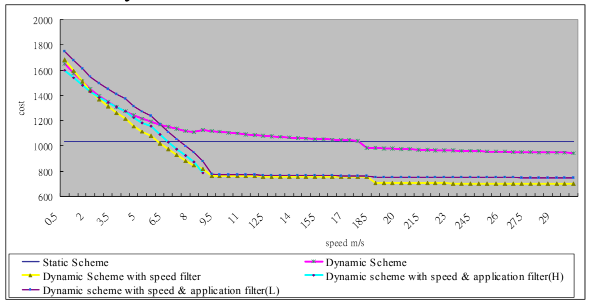


**Figure 3: Dynamic scheme A vs. static scheme**

In order to improve the performance of scheme A in the range of low speed, paging scheme B is a revision of scheme A. Paging scheme B divides the paging area into three paging zones. The system pages following a paging order are determined by the speed and application types. The average paging cost with a different speed in heterogeneous architecture is show in Figure 4. As compared to scheme A, a significant improvement has been made at a low speed. With the design of the hot-zone area and the paging order, a curve line is shown at a low speed. Scheme B reduced the paging cost at all three ranges of speeds. Hence, we concluded that dynamic scheme B is more efficient than the static scheme for heterogeneous wireless networks.

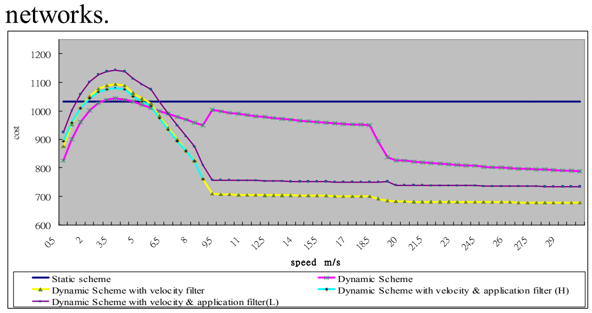


**Figure 4: Dynamic scheme B vs. static scheme**

The average paging delay with different speeds in heterogeneous architecture is shown in Figure 5. The simulation compares delays with paging using broadcast, static scheme, and dynamic scheme. The results reflect the probability of correct prediction of each paging scheme. The broadcast scheme sends paging signals to all base stations in a certain paging area, with a paging hit rate of 100% at first time. The static scheme makes no prediction, so the delay is related to the numbers of sub-paging area. The dynamic scheme considers MT movement speed to partition the paging area, so it has a higher hit rate than the static scheme.

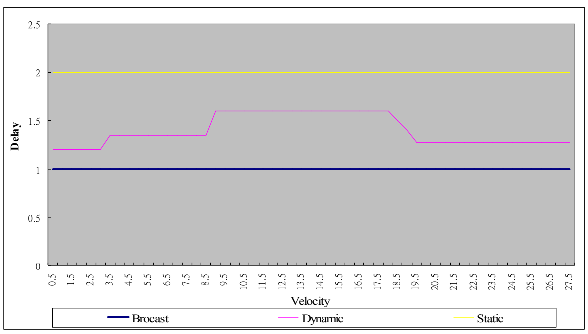


**Figure 5: Dynamic vs. static scheme B**

## 5. Conclusions

This paper proposed a speed-based mobility management for heterogeneous wireless networks. This scheme provides an efficient solution to lower the signaling transfer of location management. It also suggests a good timing for intersystem handoff. The "good timing" means the speed-based mobility management considers two factors to design the strategy manager, and it prevents the unsuitable handoff. In the other words, this concept makes seamless handoff for heterogeneous wireless network come true. Furthermore, this scheme can be generalized for other wireless network systems such as IEEE 802.16e. From the experimental results, this dynamic approach is much more efficient than the static scheme in most cases. We also observed that better performance is achieved when there are more MTs under the same geographic area. On the average, the signaling overhead is reduced up to 40%, and the paging delay is decreased at the same time. However, the dynamic scheme comes with an overhead cost of paging area construction. This overhead is handled by hardware construction and is transferred in a wired network.

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