An Inter-System Handoff Technique for the IMT-2000 System

Janise McNair **Ian F. Akyildiz**

Broadband & Wireless Networking Laboratory
School of Electrical & Computer Engineering
Georgia Institute of Technology, Atlanta, GA 30332
Email: {mcnair, ian}@ee.gatech.edu

Michael D. Bender

Department of Defense
9800 Savage Road
Fort Meade, MD 20755
Email: mdbende@afterlife.ncsc.mil

Abstract-**Next generation wireless communication is based on a global system of fixed and wireless mobile services that are transportable across different network backbones, network service providers, and network geographical boundaries. One of the most important problems for global wireless service is handoff management. In this paper, a new handoff technique is introduced which supports mobility between dissimilar networks. First, the system architecture is described, based on the concept of a boundary cell region between networks. Then a new inter-system handoff protocol is presented that uses boundary cells that allow the mobile terminal to roam into a different network. The performance of the protocol is analyzed in terms of the additional inter-system handoff signaling time and the minimum boundary cell area threshold for a successful transition within the prescribed time constraints.**

I. Introduction

Next generation wireless communication is based on a global system of fixed and wireless mobile services that are transportable across different network backbones, network service providers, and network geographical boundaries [1]. Third generation networks, such as the International Mobile Telecommunications 2000 (IMT 2000) system being standardized by the International Telecommunications Union (ITU) [2], and the Universal Mobile Telecommunications System (UMTS) standardized by the European Telecommunications Standards Institute (ETSI) [3], promise heterogeneous services to users that may roam across various regions and networks.

Ubiquitous roaming between systems requires that the radio access system support handoff between different types of networks. Handoff (or handover) management allows a call in progress to continue as the mobile terminal (MT) changes channels or moves between service areas. Since roaming users will use MTs with multiple connections that send and receive multimedia traffic with different Quality of Service (QoS) expectations, it is important to minimize the handoff delay and to accommodate MTs that may roam between networks.

Handoff management has been investigated in many papers over the past decade [4], [5]. In recent years, papers have been published that explore the problem of handoff for integrated personal communications services (PCS) systems. In [6], a signaling protocol for intersegment handoff in an integrated space/terrestrial UMTS environment was presented. Backward mobile-assisted handoff with signaling diversity was used for the intersegment handoff scheme, and the performance of the protocol was analyzed in terms of the service interruption time, execution signaling time, and the end-to-end signaling time. In [7], the effect of soft handoffs on the signaling traffic in IMT-2000 networks was investigated in terms of the processing load at each physical entity and the signaling load at each signaling link. In [8], a new handoff method for an IMT-2000 wireless system was proposed in which the handoff connection setup process was divided into the network connection setup and the radio connection setup parts. The former takes place before a handoff request by predicting the next cell location of the mobile user. However, in each of the above papers, a common handoff protocol is assumed to exist between the current and target networks.

In this paper, a new handoff technique is introduced which supports mobility between dissimilar networks with different handoff protocols. In Section II, the next generation system architecture is described, based on the concept of a boundary cell region between networks. Then in Section III, a new inter-system handoff protocol is presented that uses boundary cells that allow the mobile terminal to roam into a different network. In Section IV, formulas are derived for the additional signaling cost introduced by the protocol and the minimum boundary cell area threshold for a successful transition within prescribed time constraints. Finally, in Section V numerical results are presented, followed by the conclusion in Section VI.

II. IMT-2000 System Architecture

A. System Model

Consider the next generation wireless system shown in Fig. 1. Mobile users will be able to pass through various tiers and networks while using their MTs to communicate. The radio access network (a collection of base stations (BS) in the terrestrial networks, or fixed earth stations (FES) in the satellite networks) sends MT traffic to a cell site switch (CSS) in the current core network for routing to the final destination, and also performs handoff for MTs roaming between networks.

There are two types of roaming for the mobile user: *intra-system* roaming and *inter-system* roaming. Intra-system roaming refers to MTs that move between different tiers of the same system, i.e., between the pico, micro, and macro cells of Fig. 1. Inter-system roaming refers to MTs that move between different backbones, protocols, or ser-

0-7803-5880-5/00/$10.00 (c) 2000 IEEE

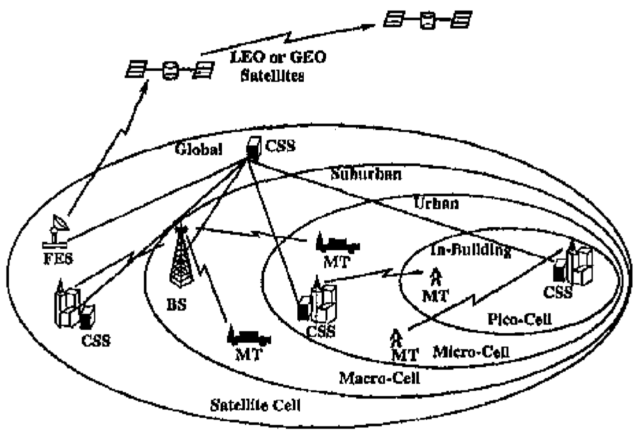

Fig. 1. Next Generation Heterogeneous Network Services

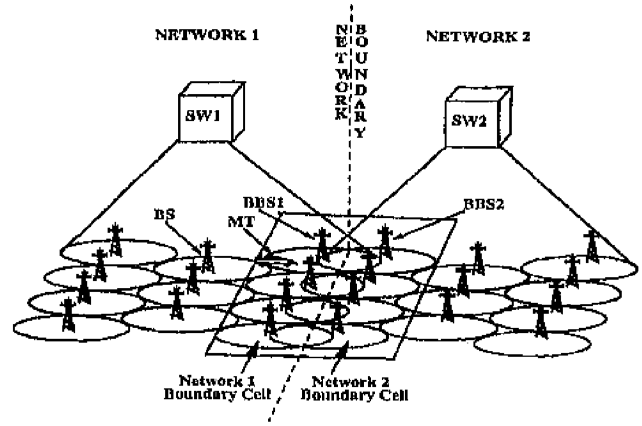

Fig. 2. Inter-System Boundary Cells

vice providers. For example, mobile users may travel from a macrocell network within the North American Interim Standard 95 (IS-95) system to a satellite PCS network, or into a region that uses the European Global System for Mobile Telecommunications (GSM).

B. *Inter-System Boundary Cells*

For the inter-system handoff protocol, we consider a boundary region between two networks, as illustrated in Fig. 2. For the case of intra-system roaming, the boundary cells can be placed at the boundaries between different tiers within the same system, while in the inter-system roaming case, the boundary cells can be placed at the boundaries between different systems. We designate the cells that overlap between the two networks as *inter-system boundary cells*. Each boundary cell is controlled by a *boundary cell base station* (BBS) which is connected to a switch (SW) in its own network, as shown in Fig. 2. While inside one of the boundary cells, the MT can transmit and receive broadcast signals from either network, depending on the MT's current configuration. Signaling and control messages passed between the boundary cell base stations and their network switches can reroute the MT's connections before the MT hands off into the new system. The goal of our protocol is to perform the system transformation before the MT begins to handoff into the next network.

Several additional issues exist for inter-system handoff [9], [10]. First, the MT must be able to communicate in more than one system. The MTs may operate in multiple modes with separate transmitter/receiver pairs, such as the satellite/terrestrial multimode terminals [9], [11], or the MTs may be reconfigured to operate in each new system [12]. Second, a technique is needed to measure and compare signals from different air interfaces and power levels. Third, transmission and signaling facilities must exist between the switches of each system. This paper

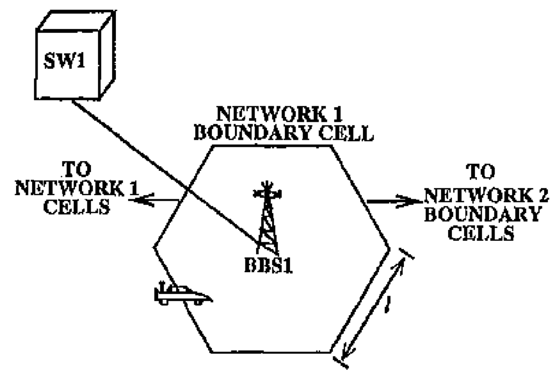

Fig. 3. Boundary Cell System

focuses on the handoff signaling procedures. Other major issues, such as dual system communication at the MT, are briefly discussed where applicable, but are beyond the scope of this paper.

The system consists of the first boundary cell that the MT reaches when preparing to cross from network 1 into network 2, as shown in Fig. 3. We assume that the cell has a hexagonal shape, where each of the six sides of the hexagon has a length of l. Within the boundary cell is the boundary base station, $BBS1$, which communicates with $SW1$. We consider the MT which has just initiated handoff to $BBS1$ and focus on the time that the MT spends within the boundary cell.

Handoff can be performed using three types of control methods: Network-Controlled Handoff (NCHO), Mobile-Assisted Handoff (MAHO), or Mobile-Controlled Handoff (MCHO). Under NCHO or MAHO, the network generates a new connection, finding new resources for the handoff and performing any additional routing operations. For MCHO, the MT finds the new resources and the network approves. Because the inter-system handoff prepares the MT to perform according to the the next system's pro-

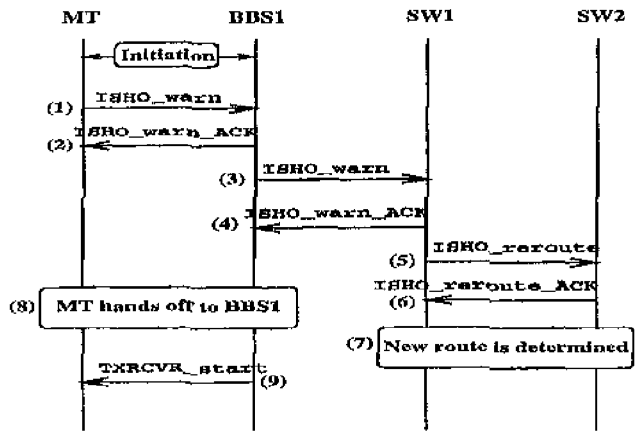

Fig. 4. Signal Flow for Handoff into a Boundary Cell

tocol, it is independent of the control techniques of the individual systems. Our protocol will perform for any changes in handoff control between systems.

III. Intersystem Handoff Procedure

To achieve intersystem handoff using boundary cells, we have developed a new set of signaling messages that must be transferred between the *boundary cell base stations* in network 1 and network 2, and the network switches (SW1 and SW2). The procedure is implemented in three phases:

1. The MT performs a handoff into an intersystem boundary cell, as shown in Figure 2. The MT uses the handoff procedure for network 1.
2. The MT performs a format transformation while within the boundary cell.
3. The reconfigured MT may handoff from the current boundary cell into a boundary cell of network 2 using the handoff procedure for network 2.

A. Handoff into a Boundary Cell

The signal flow for handoff to a boundary cell base station is illustrated in Figure 4. (Figure 4 shows the MCHO case, but modifications for MAHO and NCHO handoff control are noted where needed.) When the MT approaches the intersystem boundary cells of network 1, the MT can hear beacons from network 1 base stations as well as network 1 boundary cell base stations. Once handoff is initiated toward a boundary cell base station ($BBS1$ in Figure 4), the MT (MCHO) or the network (NCHO,MAHO) sends an *intersystem handoff warning* (*ISHO_warn*) message to $BBS1$ (step (1) in Figure 4). The *ISHO_warn* message must contain the identification of the MT, and the previous base station. $BBS1$ sends an acknowledgement of the warning message to the MT (step (2)). If either *ISHO_warn* or the *ISHO_warn_ack* messages are lost due to wireless link failures, the *ISHO_warn* message will be retransmitted until the acknowledgement is received. Next, $BBS1$ forwards the *ISHO_warn* message to $SW1$ (MCHO) (step (3)). (For NCHO and MAHO, the switch is aware of the information in the *ISHO_warn* message.)

$SW1$ returns an *intersystem handoff warning acknowledgement* (*ISHO_warn_ack*) message to $BBS1$ (step (4)) and sends an *intersystem handoff reroute* (*ISHO_reroute*) message to $SW2$, the switch for the adjacent network 2 boundary cells (step (5)). $SW2$ acknowledges the *ISHO_reroute* message (step (6)) and begins to conduct operations such as authentication, location management, encapsulation of packets, and rerouting the connection from network 1 to network 2 (step (7)).

In the meantime, the MT continues to handoff to $BBS1$ using the standard network 1 procedures (step (8)). Once the handoff is complete, $BBS1$ sends a *transmitter/receiver start* (*TXRCVR_start*) message to activate a second transmitter/receiver pair at the MT using the network 2 radio characteristics (step (9)). The MT can then receive and compare signals from network 1 and network 2 base stations and begin the second phase of the intersystem handoff procedure.

B. Format Transformation

The second phase, shown in Figure 5, is the format transformation of the MT while it resides within network 1 boundary cells. The format transformation is initiated when $BBS1$ sends a *reconfiguration begin* (*RECONFIG_beg*) message to the MT (step (10)). This message signifies the start of the download process (for reconfigurable terminals) or the mode change (for multimode terminals) (step (11)). If the *TXRCVR_start* message from step (9) was not received, the *RECONFIG_beg* message provides a redundant message to activate the appropriate transmitter/receiver. After the MT is prepared to change to the new system, the MT returns a *reconfiguration ready* (*RECONFIG_ready*) message to $BBS1$ (step (12)). (If either the *RECONFIG_beg* message or the *RECONFIG_ready* message are not received, the *RECONFIG_beg* message is retransmitted.)

The MT then remains in the ready state until a handoff to network 2 is necessary. In the meantime, when the networks have established a new route for the MT's connections, $SW1$ sends a *reroute ready* (*REROUTE_ready*) message to $BBS1$ (step (13)).

C. Handoff into the New System

Handoff from a network 1 boundary cell to a network 2 boundary cell signifies the third and final phase, and is also illustrated in Figure 5. The surrounding network 2 base stations begin monitoring the signal from the MT (for NCHO and MAHO handoff), or the MT begins monitoring the signals from the network 2 base stations (for MCHO handoff). Since the MT has activated a transmit-

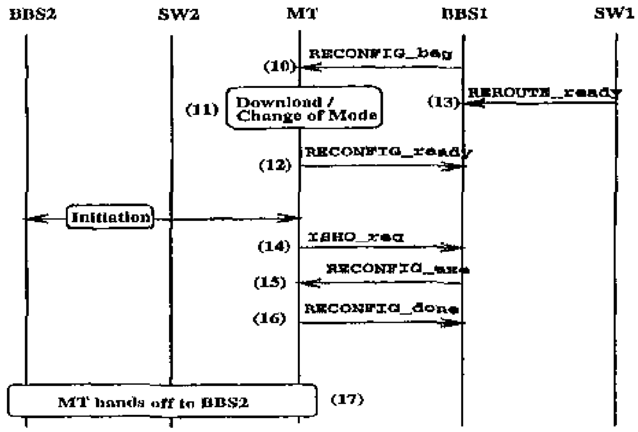

Fig. 5. Signal Flow for Handoff into the Next System

tor/receiver for each network, the MT (MCHO,MAHO) and/or the networks (NCHO) are able to measure and compare signal strength for the surrounding base stations for both systems. When handoff to a network 2 base station ($BBS2$) is initiated, the MT (MCHO) or the network (NCHO, MAHO) sends an ***intersystem handoff required*** ($ISHO\_req$) message to $BBS1$ (step (14)). $BBS1$ returns a ***reconfiguration execute*** ($RECONFIG\_exe$) message to the MT (step (15)), triggering the MT to switch to network 2 operations. (The $ISHO\_req$ message is retransmitted until the $RECONFIG\_exe$ is received.) Then the MT acknowledges the $RECONFIG\_exe$ message by sending a $RECONFIG\_done$ message (step (16)), and the MT is able to perform a network 2 handoff to $BBS2$ (step (17)). The new route is activated when the MT begins to transmit data to $BBS2$. If the $RECONFIG\_done$ message is not received, $BBS1$ will time out the MT's resources.

D. MT Movement Within the Boundary Cells

It is important to note that some of the MTs that handoff to $BBS1$ will not move from network 1 directly to network 2. For example, an MT may move from a boundary cell base station in network 2 to a boundary cell base station in network 1. Also, an MT may travel within the boundary cells of network 1 and never enter network 2. It is necessary to find out the direction of movement of the MT in order to determine if a format transformation is required. These cases are evaluated at the governing switch.

Each switch on an intersystem boundary maintains a list of the boundary cell base stations of network 1 and a list of the boundary cell base stations of network 2. The identity of the previous base station is checked with these two lists to determine which system the MT has moved from. If the previous base station is not on either list, the MT has moved from network 1 into the boundary cell region of network 1. In this case, it is necessary for $BBS1$ to prepare the MT for handoff into network 2, but to maintain the ready state until a network 2 handoff is about to occur, as described above. If the previous base station identity is found on the list of network 2 boundary cell base stations, the MT is moving from the boundary cells of network 2 into the boundary cells of network 1. Again, $BBS1$ should prepare the MT for handoff into network 2, but to maintain the ready state, to avoid a ping-pong condition. If the previous base station is listed among the network 1 boundary cell base stations, then the MT has moved within the boundary cells of network 1. The MT has already begun the re-routing and format transformation process. The MT only needs to remain in the ready state until a handoff to network 2 becomes necessary.

Several of the key issues for handoff protocols are latency, and probability of forced termination of a call. For intersystem handoff, latency may result from the additional signaling messages and from the format transformation delays. Forced termination may result from an attempted handoff to network 2 when the MT has not had time to complete the format transformation. In the next section, we estimate the impact of the intersystem handoff protocol on the total handoff time and find the minimum boundary cell area threshold for a successful transformation within the prescribed time constraints.

IV. Performance Evaluation

We now calculate the additional signaling time introduced by the inter-system handoff protocol, the minimum residency time requirements for each MT that must perform a format transformation within the boundary cell, and the minimum boundary cell area required for a desired probability of successful inter-system handoff. We consider a MT which has just initiated handoff to $BBS1$ and focus on the time that the MT spends within the boundary cell. Some modeling assumptions are made for the sake of analytical tractability [13]. We assume that the residency time is exponentially distributed, that movements of the MT are not correlated, and that the MT's direction of travel follows a uniform distribution on the interval $[0, 2\pi)$. The MTs are assumed to be uniformly distributed on the surface of the boundary cell.

A. Additional Signaling Time

The *additional signaling time*, T_s, is the total time needed to transmit and process the messages of the intersystem handoff protocol, as outlined in Fig. 4 and Fig. 5. T_s is calculated in (1) by summing the signaling time required for each of the steps:

$$T_s = \sum_{i-s} T_i, \quad (1)$$

where T_i is the time spent in performing Step (i) in Fig. 4 and Fig. 5, for $i = 1, \ldots, 16$ without Step (8). Step (8) is not included because it does not introduce additional signaling or processing time to the inter-system handoff.

The *time to send a message*, M_i, can be calculated as in (2):

$$M_i = \alpha_i + \beta_i + \gamma_i, i = 1, \ldots, 7, 9, \ldots, 16 \qquad (2)$$

where α_i is the transmission time, β_i is the propagation time, and γ_i is the processing time for the control message in Step (i).

The *transmission time*, α_i, is computed by:

$$\alpha_i = \frac{b_i}{B}, \qquad (3)$$

where b_i is the size of the control message in bits, and B is the bit rate of the link on which the message is sent.

To calculate each T_i in (1), we first consider the steps that do not require retransmission. This includes Steps (2)-(7), (9), (12)-(13), and (15)-(16). For these steps the signaling time is equal to the message time:

$$T_i = M_i \quad i = 2, \ldots, 7, 9, 12, 13, 15, 16. \qquad (4)$$

Note that it may happen that the control message for Step (7) may be sent over N hops from $SW1$, to a crossover switch between network 1 and network 2, to $SW2$. If this is the case, then the signaling time at Step (7), T_7, is computed by:

$$T_7 = N * M_7. \qquad (5)$$

Next we calculate the signaling time for the messages that may be affected by losses over the wireless link (Steps (1), (10), and (14)). Let n_f be the number of wireless link failures. Then

$$T_i = \sum_{n_f=0}^{\infty} T_i(n_f) * Prob\{n_f \ failures \ and \ 1 \ success\} \qquad i = 1, 10, 14. \qquad (6)$$

Let T_w be the waiting time to determine that the message was lost. The time to send a message when there are n_f failures is then calculated:

$$T_i(n_f) = M_i + n_f * (T_w + M_i) \qquad i = 1, 10, 14. \quad (7)$$

The signaling time, T_i, from (6) is then represented by:

$$T_i = \sum_{n_f=0}^{\infty} [M_i + n_f * (T_w + M_i)] * Prob\{n_f \ failures \ and \ 1 \ success\} \qquad (8)$$

$$= M_i + (T_w + M_i) * \sum_{n_f=0}^{\infty} n_f * Prob\{n_f \ failures \ and \ 1 \ success\} \qquad i = 1, 10, 14. \qquad (9)$$

We use the techniques in [14] to calculate the sum in (9) given a probability q that the wireless link fails. Then the signaling time, T_i, for the messages sent on the wireless link in Steps (1), (10) and (14) is finally determined by:

$$T_i = M_i + (T_w + M_i) * \frac{q}{1-q}. \qquad i = 1, 10, 14. \quad (10)$$

The last signaling time consideration is the format transformation time in Step (11). T_{11} is the time to download new settings to a reconfigurable MT (or the time to switch modes in a multimode MT). It is assumed to be a measured value and is used as a system input parameter.

The additional signaling time, T_s, (1), also affects the amount of time the MT must spend within a boundary cell. If the MT leaves the boundary cell before the transformation is complete, the MT's connections will be lost and the inter-system handoff will fail. The boundary cells must be large enough to ensure successful format transformations for MTs that will transition into the next network. In the next section, we use T_s to determine the minimum boundary cell sizes that will allow an MT to avoid an inter-system handoff failure.

B. Probability of Inter-System Handoff Failure

We now calculate the probability that the inter-system handoff will fail due to the MT leaving the boundary cell before the additional signaling for the system transformation can be completed. Let T be a random variable that takes on values of the time to the next consecutive handoff after the MT's arrival into the boundary cell, i.e., the time that the MT resides in the boundary cell. Then, the probability that the MT leaves the boundary cell before the required time, T_{req}, is:

$$P = Prob[T < T_{req}] \qquad (11)$$

Now we restrict this probability to a certain threshold, P_f. If we assume that T is exponentially distributed, then (11) becomes:

$$Prob[T < T_{req}] \ < \ P_f, \ or \qquad (12)$$

$$1 - e^{-\lambda T_{req}} \ < \ P_f, \qquad (13)$$

where λ is the arrival rate of MTs into the boundary cell. For an MT whose direction of travel is uniform on the interval $[0,2\pi)$, we find that the arrival rate, λ_{MT}, of the MT into the boundary cell is given by:

$$\lambda_{MT} = \frac{VL}{\pi S}, \qquad (14)$$

where V is the expected velocity of the MT, L is the length of the perimeter of the boundary cell, and S is the boundary cell area [15]. If we assume the boundary cell has a hexagonal shape as shown in Fig. 3, we may insert the values for the perimeter and area into (14), where each of the six sides of the hexagon has a length of l. Then the arrival rate, λ_{MT}, becomes:

$$\lambda_{MT} = \frac{2V}{\pi l \sin(\pi/3)} \quad . \tag{15}$$

The value of l will then be used to determine the minimum boundary cell area.

C. Minimum Boundary Cell Area

From (13) and (15), we find that the minimum required length for one side l of a hexagonal boundary cell is:

$$l > \frac{2VT_{req}}{\pi \log(\frac{1}{1-P_f}) \sin(\pi/3)}, \tag{16}$$

so that the restriction on the boundary cell area, A_{cell}, is:

$$A_{cell} > \frac{6l^2}{2} \sin(\pi/3). \tag{17}$$

V. Numerical Results

To obtain values for the additional signaling time, T_s, (1), many system dependent parameters must be considered in (2) and (3), including the bit rates, B, of the wireline and wireless links, the propagation times, β, of each link, and the processing times, γ, at the MT, BSs and SWs. In addition, to obtain values for boundary cell size between different tiers within a single system or between different tiers in different systems in (16) and (17), we consider the velocities, V, for the MTs according to their tier, as designated by recent IMT-2000 and UMTS proposals [6], [16], [17], [18].

A. System Parameters

The parameters used to analyze the system are listed in Table I. The MT, BS, and SW processing times, γ, the message size b, and the number of hops, N, in (3), (2) and (5) are system input parameters.

B. Impact of the Additional Signaling Time

Table II shows the additional signaling time, T_s, introduced by the inter-system handoff protocol and calculated by (1). T_s is calculated for the various tiers to be supported by the IMT 2000, as well as for the Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO) satellite networks. For example, consider MTs traveling from an indoor environment (i.e., a pico cellular system) to an outdoor pedestrian environment (i.e., a micro cellular system). According to the assumed system parameters given in Table I and the numerical results in Table II, the MT will need to spend $T_s = 49$ additional milliseconds of time in the boundary cell in order to prepare for the inter-system handoff. Similarly, for an MT on a high speed train (macro cellular system) traveling into a rural area that requires LEO satellite coverage, the MT will need $T_s = 120$ additional milliseconds of time at the system boundary in order to be ready to handoff into the LEO satellite system.

The additional signaling time, T_s, increases the amount of time required to perform a handoff. The total inter-system handoff time is the sum of the additional signaling time, T_s, and the nominal handoff values for each tier, T_{17}. For the indoor and pedestrian (pico- and micro-cell) systems, the nominal values for the North American Personal Access Communications System (PACS) and the European Digital European Cordless Telecommunications (DECT) system are used [4], while for macrocell and satellite handoff times, the nominal values for the European Global System for Mobile Communications (GSM) system are used. Due to the large expected bit rates of the lower tiers, and the large propagation times of the MEO and GEO satellite systems, we see that the additional signaling time, T_s, in the inter-system handoff has a very large impact on the total handoff time, with increases of over twice the nominal handoff time. Thus, to implement the procedure, these systems will require advanced coding techniques to reduce the need for retransmitted messages and multimode MTs that do not use a download period. On the other hand, macro cellular networks and LEO satellite networks experience only a 10% to 20% increase in handoff time. The system transformation can be accommodated for these networks without a great change in handoff delay.

C. Impact of Boundary Cell Size on the Probability of Inter-System Handoff Failure

Fig. 6 and 7 show the probability of inter-system handoff failure, P_f, for different values of the boundary cell area, A_{cell}, as calculated in (16) and (17). (Differences in scale between the graphs should be noted.) To be prepared for handoff into the next system with a probability P_f, the MT will need an area the size of A_{cell} in which to perform the inter-system handoff protocol operations and the format transformation before it enters the next system. The smaller the boundary cell, the less time the MT has to perform the format transformation. Thus, the higher the probability of inter-system handoff failure, i.e., that the transformation is not completed, and the MT enters the next network without the ability to communicate in the new network. We found that the boundary cell thresholds are reasonable according to the tier and network type. For example, for the terrestrial network results shown in Fig. 6, a probability of failure of $P_f = 2\%$ allows a mobile user transferring from a picocell to a microcell a minimum boundary cell area of about $A_{cell} = 6$ square meters. This may be equivalent to a person roaming from an urban office building to the public downtown network

Bit Rates (B) [16], [17]		Propagation Times (β) [6]	
Wireline Link	155 Mbps	Wireline Link	500 μsec
Wireless Link		Wireless Link	
Low Mobility	2 Mbs	Terrestrial	2 msec
Medium Mobility	384 Kbps	LEO	5.2-15.2 msec
Vehicular Mobility	144 Kbps	MEO	69-96 msec
High Mobility	64 Kbps	GEO	239-270 msec
Satellite Mobility	144 Kbps		
Processing Times (γ)		**MT Velocities (V) [18], [10]**	
Switch	0.5 msec	Low Mobility	3 km/hr
Base Station	0.5 msec	Vehicular Mobility	10-100 km/hr
Mobile Terminal	0.5 msec	High Mobility	300 km/hr
		Nominal Handoff Times (T_{17}) [4]	
Message Size (b)	50 bytes	PACS	20 msec
Number of Hops (N)	3	DECT	50 msec
Download Time (T_{11})	10 msec	GSM	1 sec
Link Failure Probability (q)	0.5		

TABLE I

SYSTEM PARAMETERS

	Indoor (picocell)	Pedestrian (microcell)	Vehicular (macrocell)	High Spd (macrocell)	Satellite Cells		
					LEO	MEO	GEO
V, MT Velocity [18]	3 km/hour	3 km/hour	10 - 100 km/hour	300 km/hour	Variable	Variable	Variable
B, Bit Rate [16], [17]	2 Mbps	384 Kbps	144 Kbps	64 Kbps	144 Kbps	144 Kbps	144 Kbps
T_s, Add'l Signaling Time (Eq. 1)	49 msec	59 msec	80 msec	120 msec	0.1 - 0.2 sec	0.7 - 1 sec	2.4 - 2.7 secs
T_{17}, Nominal Handoff Time [4]	20msec (PACS)	50msec (DECT)	1 sec (GSM)	1 sec (GSM)	1 sec (GSM)	1 sec (GSM)	1 sec (GSM)
Total Handoff Time	69 msec	109msec	1.1 secs	1.1 secs	1.1-1.2 secs	1.7-2 secs	3.6-4.1 secs

TABLE II

ADDITIONAL SIGNALING TIME REQUIRED TO PERFORM INTER-SYSTEM HANDOFFS FOR EACH OF THE IMT-2000 TIER DESIGNATIONS

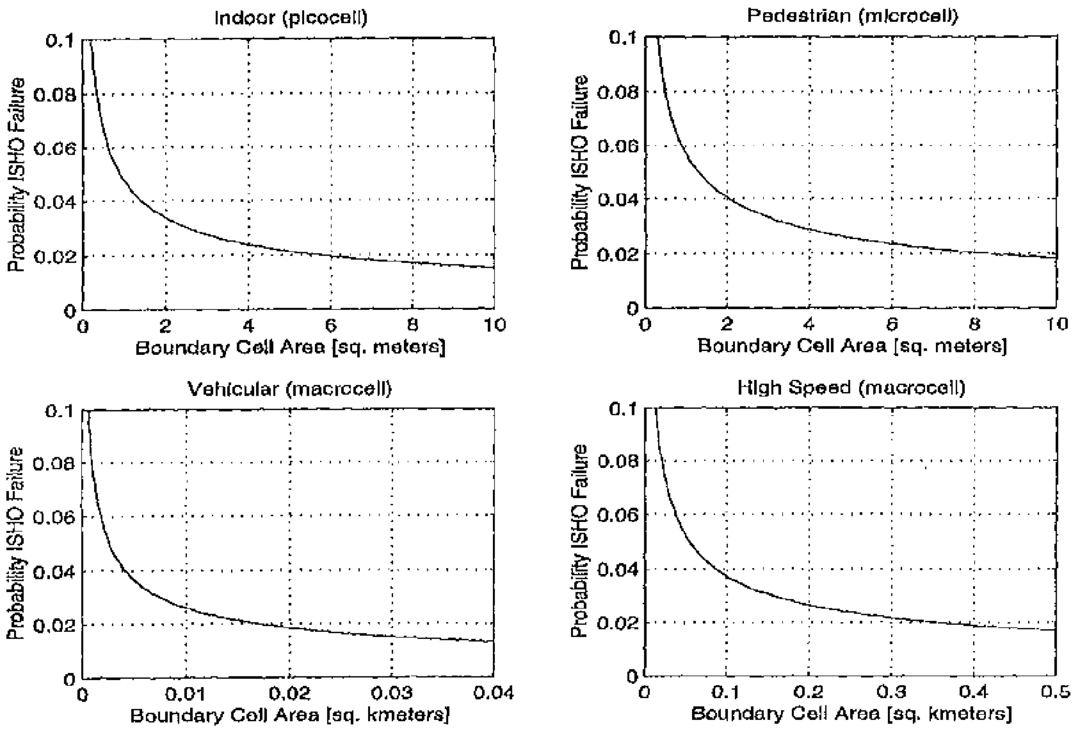

Fig. 6. Probability that the MT will leave the Boundary Cell before the Inter-System Handoff is Completed for Terrestrial Cell to Terrestrial Cell Format Transformations

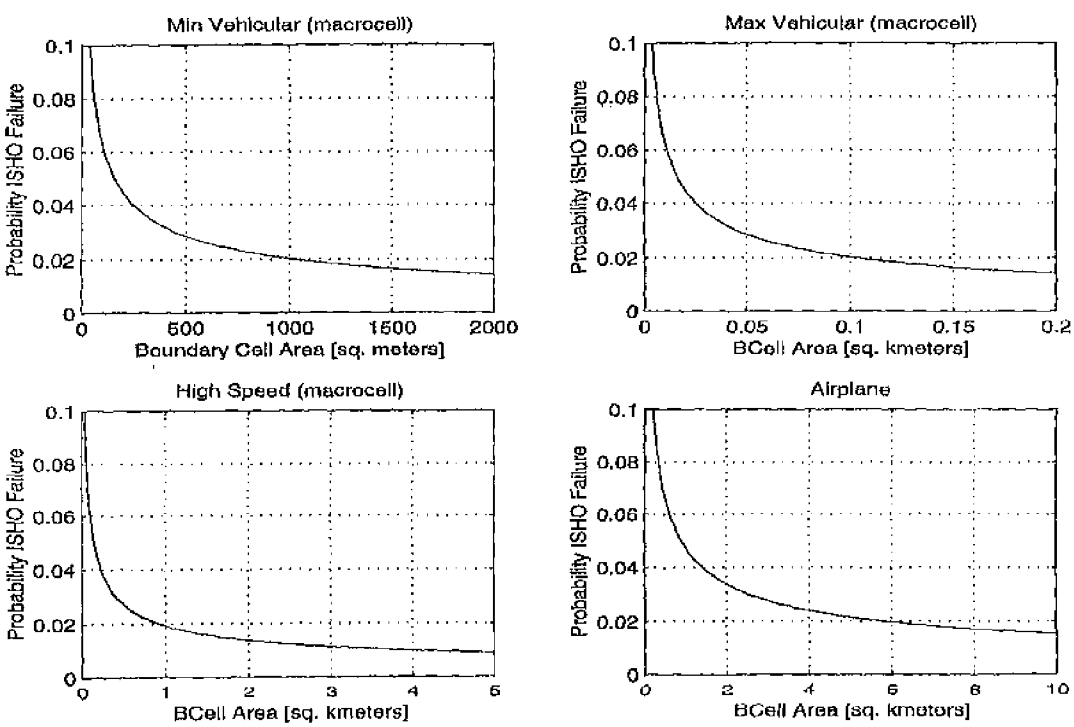

Fig. 7. Probability that the MT will leave the Boundary Cell before the Inter-System Handoff is Completed for LEO Satellite Cell to Terrestrial Cell Format Transformations

with a lobby area performing the function of the boundary cell. Similarly, a mobile user on a high speed train needs to pass through a boundary cell area of at least $A_{cell} = 0.4$ square kilometers in order to successfully transform to a satellite system with a 2% probability of failure.

The transition from a satellite cell to a new network requires a much larger minimum boundary cell area, A_{cell}, than the terrestrial macrocell and microcell transitions, due to the increase in propagation time, β. Fig. 7 shows the boundary cell area thresholds, A_{cell}, for the probability of failure, P_f, as calculated in (16) and (17), for a LEO satellite network transition to several terrestrial tiers. The minimum boundary cell thresholds, A_{cell}, are several orders of magnitude greater for the LEO satellite network. However, in consideration of the increased speeds and the LEO satellite cell size, the boundary cell remains reasonable for system transformations.

VI. Conclusion

This paper presented the new procedures and signaling messages that are necessary to support handoff between dissimilar tiers or networks within an IMT-2000 system. We introduced the concept of inter-system boundary cells that can be used in an inter-system handoff protocol to prepare the mobile terminal for communication in the new system. The added signaling times introduced by the inter-system handoff protocol were calculated for various tiers and for various satellite networks. The extra signaling time has a very large impact on the overall handoff time for picocell and microcell networks as well as MEO and GEO satellite networks, due to the high bit rates at the lower terrestrial tiers and the large propagation times of the satellite networks. However, for macrocell networks and LEO satellite networks, the system transformation can be accommodated without a great increase in handoff delay over nominal values for the GSM system. The minimum boundary cell area was found in terms of the probability of meeting the minimum residency time required for successful system transformation. The minimum boundary cell thresholds are several orders of magnitude greater for the LEO satellite network. In consideration of the increased speeds and the LEO satellite cell size, the boundary cell remains reasonable for system transformations.

References

[1] I.F. Akyildiz, J. McNair, J.S.M. Ho, H. Uzunalioğlu, and W. Wang, "Mobility management in next generation wireless systems," *Proceedings of the IEEE*, vol. 87, no. 8, August 1999.

[2] R. Pandya, D. Grillo, E. Lyckselli, P. Mieybegue, H. Okinaka, and M. Yabusaki, "IMT-2000 standards: Network aspects," *IEEE Personal Communications*, pp. 20–29, August 1997.

[3] A. Samukic, "UMTS universal mobile telecommunications system: Development of standard for the third generation," *IEEE Transactions on Vehicular Technology*, vol. 47, no. 4, pp. 1099–1104, November 1998.

[4] A. Noerpel and Y.B. Lin, "Handover management for a PCS network," *IEEE Personal Communications Magazine*, pp. 18–24, December 1997.

[5] G.P. Pollini, "Trends in handover design," *IEEE Communications Magazine*, vol. 34, no. 3, pp. 82–90, March 1996.

[6] N. Efthymiou, Y. F. Hu, and R. Sheriff, "Performance of intersegment handover protocols in an integrated space/terrestrial-UMTS environment," *IEEE Transactions on Vehicular Technology*, vol. 47, no. 4, pp. 1179–1199, November 1998.

[7] Y. H. Kwon, D. K. Kim, J. H. Jung, M. K. Choi D. K. Sung, H. K. Yoon, and W. Y. Han, "Effect of soft handoffs on the signalling traffic in IMT-2000 networks," in *Proceedings of IEEE GLOBECOM '98*, November 1998.

[8] K. Ushiki and M. Fukazawa, "A new handover method for next generation mobile communication systems," in *Proceedings of IEEE GLOBECOM '98*, November 1998, pp. 1118–1123.

[9] V.K. Garg and J. E. Wilkes, "Interworking and interoperability issues for north american PCS," *IEEE Communications Magazine*, vol. 34, no. 3, pp. 94–99, March 1996.

[10] Y.B. Lin and I. Chlamtac, "Heterogeneous personal communication services: Integration of PCS systems," *IEEE Communications Magazine*, vol. 34, no. 9, pp. 106–113, September 1996.

[11] N. W. Whinnett, "Handoff between dissimilar systems: General approaches and air interface issues for TDMA systems," in *Proceedings of the IEEE Vehicular Technology Conference (VTC) '95*, July 1995, pp. 953–957.

[12] P. Lettieri and M.B. Srivastava, "Advances in wireless terminals," *IEEE Personal Communications Magazine*, vol. 6, no. 1, pp. 6–19, February 1999.

[13] Y.B. Lin, "Modeling techniques for large-scale PCS networks," *IEEE Communications Magazine*, vol. 35, no. 2, pp. 102–107, February 1997.

[14] L. Kleinrock, *Queueing Systems*, Wiley, 1975.

[15] R. Thomas, H. Gilbert, and G. Mazziotto, "Influence of the moving of the mobile stations on the performance of a radio mobile cellular network," in *Proceedings of the 3rd Nordic Seminar*, September 1988, pp. 1–9.

[16] W. Mohr, "European proposal for IMT-2000 part ii:UTRA TDD," in *IMT-2000 Workshop*. Georgia Center for Advanced Telecommunications Technology, November 1998.

[17] M. Unsoy et al., "IMT-2000: Next generation wireless mobile systems," in *Proceedings of IEEE ICC '98*, June 1998, Services, Applications, and Systems Session.

[18] J.G. Markoulidakis, G.L. Lyberopoulos, D.F. Tsirkas, and E.D. Sykas, "Mobility modeling in third-generation mobile telecommunications systems," *IEEE Personal Communications Magazine*, pp. 41–56, August 1997.