Performance Analysis of the Anchor Radio System Handover Method for Personal Access Communications System

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Abstract

This paper presents an analysis of the Anchor Radio System (RS) handover method for Personal Access Communications System (PACS). This handover method provides a simple yet effective solution without adding new requirements to the existing network infrastructures. Based on this technique, inter-RS and inter-switch handovers can be achieved using a new RS-to-RS interface called Inter-RS Interface (IRI). This paper first describes the use of the IRI Protocol among PACS based RSs. Then it proposes an analytical model for the Anchor RS handover method to determine the expected handover delay under given mobility, call duration and signaling delay parameters.

1 Introduction

This paper presents an analysis of a handover method, known as the Anchor Radio System (RS) handover method, for the Personal Access Communications System (PACS)[1]. This technique performs both inter-RS and inter-switch handovers. The generic term Radio System (RS) is used to cover both the *Radio Port* and the *Radio Port Controller* functionalities (e.g., RP and RPCU in PACS, see Figure 1). This relies on a new RS-to-RS interface referred to in this paper as the *Inter-RS Interface* (IRI).

In the anchor RS method[5], the RS through which the call was originally established is called the *anchor RS*. This RS acts as the single interface point between the Public Switched Telephone Network (PSTN) and the radio systems for the entire duration of the call. During inter-RS handovers, all bridging is performed in this anchor RS by establishing connections between the new RS and the anchor RS. That is, no matter how many inter-RS handovers occur throughout the entire call duration, the anchor RS always retains an ISDN connection to the original switching system and bridges that connection through to the new RS that is currently providing the radio link to the subscriber unit.

This paper introduces an analytical model for the Anchor RS handover method. An Embedded Markov chain model is used to capture the mobility and calling pattern of a subscriber unit. The expression for the handover delay is developed and analytical results are presented in this paper which demonstrate the performance of the handover method under various system parameters.

This paper is organized as follows. Section 2 gives an overview of PACS and the architectural assumptions employed throughout this paper. Section 3 introduces the IRI and describes the IRI message flow. Section 4 presents the performance evaluation for the Anchor RS handover method. The conclusion is given in Section 5.

2 Overview of PACS and its Architecture

Personal Access Communications System (PACS)[1] is a low power radio system for both Personal Communications Service (PCS) applications and for fixed wireless loop applications. PACS has become an industry (ANSI) standard in July 1995.

The PACS is very economical for deployment in high density areas, especially microcell. The average transmitter power of the PACS handset is 0.025 watt as compared to 0.6 watt from the handsets of most high power systems. The automatic power control feature may reduce this low power further if the PACS handset is close to a radio port. PACS uses the CCITT standard 32 Kb/s ADPCM speech coder and can maintain very good voice quality with two or three speech coders in tandem. PACS architecture is also designed to have excellent capability for non-blocking priority and

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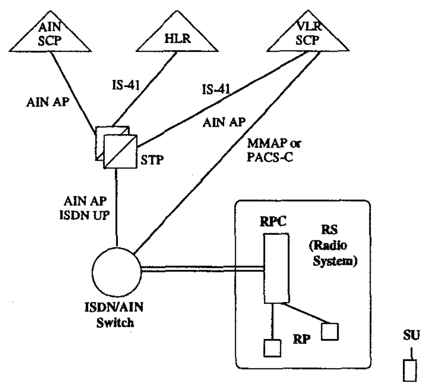


AIN AP:	Advanced Intelligent Network Application Part	**RP:**	Radio Port
MMAP:	Mobility Management Application Protocol (being developed in T1S1)	**RS:**	Radio System
HLR:	Home Location Register	**SU:**	Subscriber Unit
IS-41B:	Interim Standard 41B for Automatic Roaming [2]	**SCP:**	Service Control Point
ISDN:	Integrated Services Digital Network	**SS7:**	Signaling System No. 7
ISDNUP:	ISDN User Part of SS7	**STP:**	Signaling Transfer Point
RPC:	Radio Port Control	**VLR:**	Visitor Location Register
		PACS-C:	PACS C Interface

Figure 1: Generic Architecture

emergency (i.e., 911) calls which are protected by non-blocking priority handovers in case of fading on radio links.

A number of leading companies including Motorola, Hughes Network Systems, NEC and Fujitsu have developed commercial prototype PACS products. Currently, Southwestern Bell is completing a field trail of PACS. Bellcore has also developed a PACS operation support software known as MobiSoft. Deployments of PACS for commercial services are expected to start in 1996.

Figure 1 shows a generic architecture. It is assumed that throughout these inter-RS handover events, the ISDN/AIN Switch is unencumbered by the operation of the radio system and the Subscriber Unit (SU) under the anchor RS based handover technique. In addition, this method does not entail changes to SS7.

The *AIN/ISDN Switch* is unaware of handovers. When a circuit switched data type connection is used between RSs, the switch supports the establishment of the connection between RSs and relays handover related messages over the connection between RSs.

The *AIN Service Control Point (SCP)* and *Home Location Register (HLR)* have no roles in the anchor RS-based handover.

The *Visitor Location Register (VLR)* has a secondary role in the anchor RS-based handover. Once the RSs accomplish a handover, they may inform the VLR of the event.

The *Radio System (RS)* is assumed to include the Radio Port Controller (RPC) and the Radio Ports (RPs). In addition to the interfaces to the PSTN/ISDN, the SU, and VLR, the RS needs to support an additional interface, called the Inter-RS Interface (IRI), as shown in Figure 2. The IRI is use for the anchor RS-based intra-switch and inter-switch handovers. An anchor RS and its AIN/ISDN switch serve a user at the beginning of a call and remain on the call even though many other RPCUs may provide the radio link to the user during later portions of the call.

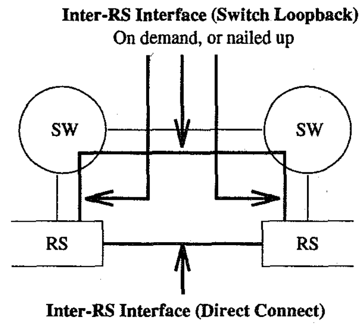


Figure 2: IRI Transmission Alternative

3 Inter-RS Interface and its Protocol

Two schemes are presently envisioned as shown in Figure 2. In the case of the first scheme, known as *switch loopback* (RS-SWs-RS), RSs establish a digital transmission path between RSs when an inter-RS handover takes place. In the second scheme, known as *direct-connect*, RSs use pre-provisioned transmission facilities to transfer the voice path and signaling for the call between RSs. Both of these interconnection schemes require similar "in-channel" call flow signaling to occur when an inter-RS handover takes place. At the completion of an inter-RS handover, there is a single connection between the anchor RS, where the call was originally established, and the target RS. The control of service features (e.g., call-waiting, three-way calling) will remain at the anchor RS for the duration of the call. For handovers to occur between RSs it must be possible i) to transfer the voice path for the call between RSs and ii) to allow RSs to exchange signaling messages. Both functions are handled by using the same digital transmission path (i.e., IRI) between two RSs. This is accomplished by dividing the digital channel into two subchannels: the *User-Information* subchannel and the *RS-RS Signaling* subchannel.

Figure 3 shows the protocol architecture developed for use on the RS-RS Signaling subchannel by the anchor RS-based handover procedures. Note that Figure 3 shows only the relevant protocol stacks. For simplicity, the interfaces and protocol stacks for the RS/VLR interfaces are not shown. Also, note that the term "layer" is used to categorize the functions of a given protocol. Any layer in this architecture may or may not corre-

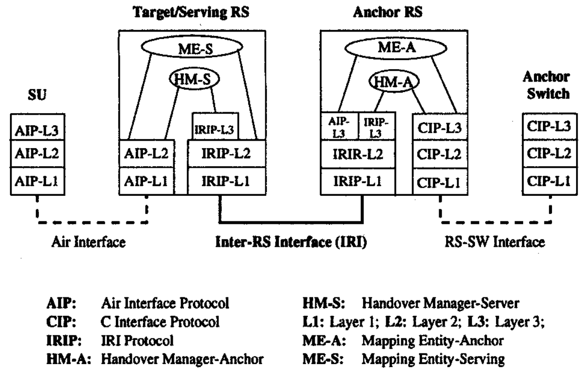


Figure 3: Protocol Architecture on IRI

spond to protocol functions in the International Standards Organization's (ISO's) Open System Interconnection (OSI) model.

It is assumed the air interface between the SU and RS uses a 3-layer protocol referred to by the *Air Interface Protocol* (AIP). The architecture also assumes that the RS and Switch use a protocol referred to by the generic name, the *C Interface Protocol* (CIP). The CIP may contain call control and mobility management procedures defined for the PACS system or may contain the generic C protocols being defined in T1 and TIA.

The interface between two RSs is called the Inter-RS Interface (IRI). The protocol running on this interface is named the *IRI Protocol* (IRIP). As shown in Figure 3, the IRIP has a 3-layer architecture. The IRIP-L1 is responsible for physical level transmission of the bit stream between the RSs. For a 64 Kb/s digital transmission path, the RS-RS signaling subchannel is 32 Kb/s wide. The remaining 32 Kb/s are used for voice or data in various rates. ITU-T Recommendations I.460[2] and V.110[3] are also used for multiplexing of the subrate subchannels and rate adaptation. The IRIP-L2 provides typical "link" layer functions with the necessary framing and retransmission capabilities to transport IRIP-L3 messages between two RSs. The IRIP-L2 will also have a multiplexing function to provide transport services to a number of higher-layer "users". LAPD, the Link Access Procedure on the D Channel for ISDN, has been selected as the basis for the IRIP-L2. The IRIP-L3 is responsible for providing mechanisms to transfer various signals that two RSs will exchange to perform the handover.

An underlying feature of the anchor RS-based handover method is that the anchor RS is the "single point of the contact" for the call. This indicates that anything that has to do with the call (e.g., three-way calling, call waiting) must be known by the anchor RS. These call related operations are handled usually in Layer 3 (L3) of the Air Interface Protocol (AIP). For example, to

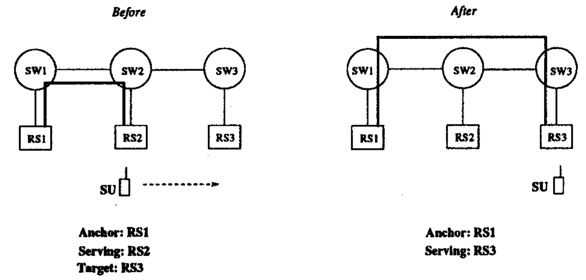


Figure 4: Handover-to-Third Scenario

start a three-way call, typically, the SU sends a Call Request message to the serving RS by using the air interface Layer 3 protocol. It is important that this message reaches the anchor RS as soon as possible, so that the anchor RS can take the appropriate actions by interworking with the AIN/ISDN and the VLR. The need for speedy transfer of the AIP-L3 messages to the anchor RS resulted in the decision that the target RS will not terminate AIP-L3.

Figure 3 also shows four new functional entities (i.e., a group of functions) in the Radio Systems: 1) the *Mapping Entity-Serving* (ME-S) in the target/serving RS to get the AIP-L3 messages from the AIP-L2 protocol and provide them to the IRIP-L2 protocol; 2) the *Mapping Entity-Anchor* (ME-A) in the anchor RS to provide a bridging between the AIP-L3 messages and the CIP-L3 messages; 3) the *Handover Manager-Serving* (HM-S) in the target/serving RS to provide a mapping between the AIP-L2 messages and the IRIP-L3 messages; and 4) the *Handover Manager-Anchor* (HM-A) in the anchor RS to provide a similar function to map the IRIP-L3 signals to the appropriate CIP-L3 messages.

The following set of IRIP-L3 messages is defined to carry out the functions described above.

IRIP REQUEST: Used by the target RS to signal the identifier of the radio call needing the handover and to request the "bridging" function from the anchor RS.

IRIP REQUEST ACK: Used by the anchor RS to acknowledge the receipt of the identity of the radio call.

IRIP EXECUTE: Used by the anchor RS to notify the target RS of the completion of the "bridging" request.

IRIP COMPLETE: Used by the target RS to inform the anchor RS that the handover has been completed.

Call flow diagrams describing the procedures necessary for the anchor RS-based handover method are provided in the following.

For the anchor RS-based handover, there are three distinctive scenarios: 1) Handover-Forward, 2) Handover-to-Third, and 3) Handover-Back-to-Anchor.

Handover-Forward: In this scenario, it is assumed

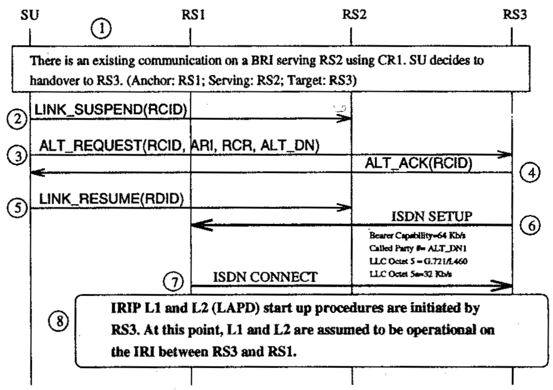


Figure 5: PACS Message Flows for Handover-to-Third Scenario

that RS1 is "serving" the SU (i.e., RS1 is the serving as well as the anchor RS). A decision is made to handover to another RS (i.e., RS2 becomes the target RS). After the handover is complete, the SU is served by RS2 (i.e., RS2 becomes the serving RS). The user info path between the SU and the other party on the call is now connected through the handover interface between RS1 and RS2 (the anchor, RS1, bridges the path between the switch and itself with the path in the handover interface).

Handover-to-Third: This scenario is depicted in Figure 4. In this scenario, it is assumed that the call is being carried on an IRI: RS2 is "serving" the SU and RS1 is the anchor RS. A decision is made to handover to another RS (i.e., RS3 becomes the target RS). The IRI between the anchor RS and the old serving RS is now disconnected. After the handover is complete, RS3 becomes the serving RS. The user info path between the SU and the other party on the call is now connected through the handover interface between RS1 and RS3 (the anchor, RS1, bridges the path between the switch and itself with the path in the handover interface).

Handover-Back-to-Anchor: In this scenario, it is assumed the call is being carried on a IRI and a decision is made to handover to the anchor RS (i.e., RS1 becomes the target RS again). After the handover is completed, RS1 becomes the serving RS. The IRI between the anchor and old serving RS is disconnected. The path between the SU and the other party on the call is now connected solely through the anchor RS.

Note that from the message flows' perspective, handover-back to a non-anchor old serving RS is the same as the Handover-Forward scenario.

The primary focus of the anchor RS-based handover flows and procedures described in this paper is based on the inter-Radio System handovers. It is assumed that inter-switch handovers do not require new procedures since switches are assumed to be fully digitally connected and they are not aware of the inter-RS handovers.

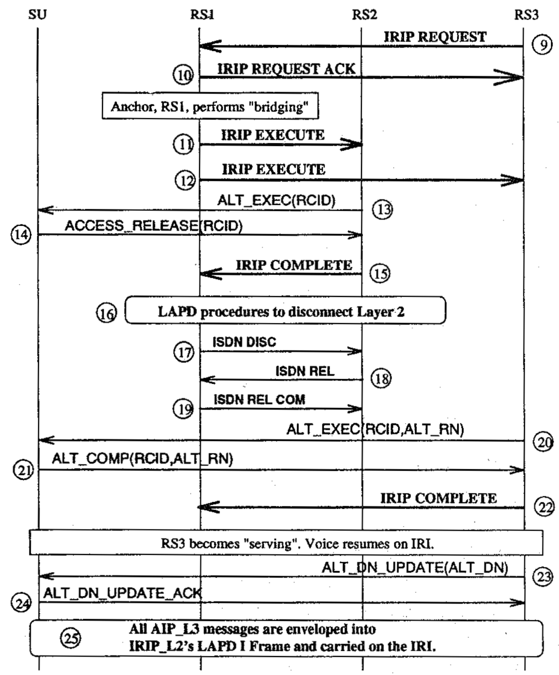
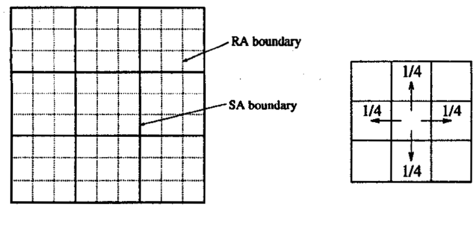


Figure 6: PACS Message Flows for Handover-to-Third Scenario (Cont.)

Intra-RS handovers are assumed to take place within the same RS. As a result, there is no impact on the anchor RS-based handover procedures.

In the following, the message flows for the "handover-to-third" scenarios are provided for PACS. The message flows for the other scenarios and for the generic air interface messages are described in detail in TR-INS-001313[1]. For the message flows in this paper it is assumed that the IRI is an on-demand circuit-switched-data-type B-Channel (BRI or PRI) established by the ISDN call setup procedures.

Figure 5 shows the message flows used during the handover initiation and handover interface setup steps between the target and the anchor RSs. Figure 6 shows the PACS message flows during the handover execution and completion steps. Note that there is already an IRI between the serving RS and the anchor RS. In steps 2, 3, 4, 5, 13, 14, 20, 21, 23 and 24, PACS specific AIP-L2 messages are exchanged. In steps 6, 7, 17, 18 and 19 ISDN specific messages are exchanged. The IRIP specific messages as shown in bold are exchanged in steps 9, 10, 11, 12, 15 and 22.



(a) RAs and SAs in a PACS (b) Routing probability

Figure 7: PACS Coverage Area with Square RAs

4 Performance Evaluation

4.1 Analytical Model

We assume that the area served by each RS, the *RS coverage area* (RA), is square-shaped and the area served by each switch, the *switch coverage area* (SA), contains $k \times k$ RAs arranged in a square. Figure 7(a) shows an example of a PACS service area which contains 81 RAs. In Figure 7(a), each SA contains 9 RAs arranged in a square such that $k = 3$. As discussed before, the anchor RS and the anchor switch are the RS and the switch, respectively, through which the call was originally established. Here we define the anchor SA as the SA of the anchor switch. Similarly, the anchor RA is the RA belonging to the anchor RS.

When a SU departs from a RA, we assume there is an equal probability (i.e., 0.25) that any one of the four neighboring RAs is selected as the destination. Figure 7(b) shows the routing probability for the square RA configuration. We assume that calls (incoming and outgoing) may be established any time regardless of the current location of the SU. A connection, once established, will continue until it is terminated by the mobile subscriber.

Let t_c and t_m to be independent and identically distributed random variables representing the call duration time and the RA residence time, respectively. We assume t_c to be exponentially distributed with rate λ_c. We also assume the probability density function of t_m to be $f_m(t)$ with Laplace transform $f_m^*(s)$ and mean $1/\lambda_m$.

We measure the performance of the Anchor RS handover method by the expected delay of the handover operation. The handover delay is defined as the total time required to set up an IRI from the anchor RS to the new serving RS and to release the IRI between the anchor RS and the old serving RS. As handover is necessary only when there is a call in progress, our objective is to study the effect of the mobility and call duration parameters on the handover delay during a call. This is achieved by analyzing a hypothetical SU which is continuously connected to the network such that as soon as a call is terminated, a new call is immediately established by the SU. The duration of each call is exponentially distributed with rate λ_c and the SU travels within the PACS service area based on the mobility assumptions as described above.

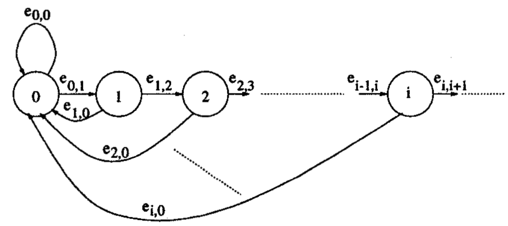


Figure 8: Embedded Markov Chain Model

Figure 8 shows an Embedded Markov chain which models the mobility and calling pattern of the SU. The state of the Embedded Markov chain, i, is defined as the number of RA crossings (handovers) since the beginning of the last call. State transition occurs immediately before a handover by the SU. Since a handover will occur right after a state transition, the number of handovers since the beginning of the call is $i + 1$. A transition from state i to state $i + 1$ occurs when there is no call termination between the $(i + 1)^{th}$ and the $(i + 2)^{th}$ handovers. Similarly, a transition from state i to state 0 occurs when the call terminates between the $(i + 1)^{th}$ and the $(i + 2)^{th}$ handovers. The probability that one or more call terminations occur between two handovers, denoted by ρ, is

$$\rho = \int_{t=0}^{\infty}(1 - e^{-\lambda_c t}) f_m(t)dt = 1 - f_m^*(\lambda_c) \quad (1)$$

and the state transition probability from state i to state j, denoted by $e_{i,j}$, is

$$e_{i,j} = \begin{cases} 1 - \rho & \text{for } j = i + 1 \\ \rho & \text{for } j = 0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

We assume p_i to be the equilibrium state probability of state i. The expression for p_i ($i \geq 0$) in terms of p_0 is

$$p_i = (1 - \rho)^i p_0 \quad (3)$$

Using the law of total probability, the equilibrium state probability of state 0 is obtained as

$$p_0 = \rho \quad (4)$$

We assume that the switch loopback type IRI as described in Section 3 and Figure 2 is used such that communications between two RSs is routed through one or more intermediate switches. As described in Section 3,

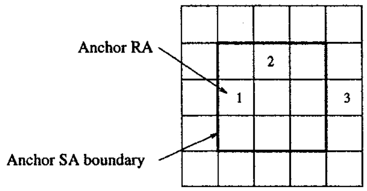


Figure 9: RS Coverage Areas (RAs)

the handover operation involves the exchange of signaling messages between the anchor RS and the old and new serving RSs. Depending on the location of the SU before and after the handover, the number of switches visited by the signaling messages varies. As a result, the handover delay is location dependent. We classify the location of each SU into the following three types:
HOME: The SU is located at the anchor RA (e.g., RA 1 in Figure 9).
LOCAL: The SU is located at an RA other than the anchor RA in the anchor SA (e.g., RA 2 in Figure 9).
REMOTE: The SU is located outside of the anchor SA region (e.g., RA 3 in Figure 9).

Assuming that the SU has performed n handovers since the beginning of its last call, Table 1 shows the eight possible combinations of the location types, **HOME**, **LOCAL** and **REMOTE**, when an additional handover, the $(n+1)^{th}$ handover, is performed. Combinations **A1** to **A8** represent eight possible types of handover. The signaling delay as well as the number of signaling messages required for each of these types of handover are different. In Section 3 we described three handover scenarios: Handover-Forward, Handover-to-Third and Handover-Back-to-Anchor. Handover types **A1** and **A2** belong to the Handover-Forward scenario; handover types **A4**, **A5**, **A7** and **A8** belong to the Handover-to-Third scenario; handover types **A3** and **A6** belong to the Handover-Back-to-Anchor scenario.

Figures 5 and 6 show the signaling message flow during handover. It can be seen that five signaling messages are exchanged between the anchor RS and the old serving RS while six signaling messages are exchanged between the anchor RS and the new serving RS. Another ten signaling messages are exchanged between the SU and the new and old serving RSs. We assume the total signaling delay between the anchor RS and the old serving RS during handover when the original location of the SU is **LOCAL** and **REMOTE** to be a_1 and a_2, respectively. Similarly, we assume the total signaling delay between the anchor RS and the new serving RS during handover when the new location of the SU is **LOCAL** and **REMOTE** to be b_1 and b_2, respectively. The values for these signaling delay parameters depend on the configuration and the signaling load on the network. We consider several sets of signaling delay values

Type	After n handovers	After $n+1$ handovers	Delay
A1	**HOME**	**LOCAL**	$h_1 = b_1$
A2	**HOME**	**REMOTE**	$h_2 = b_2$
A3	**LOCAL**	**HOME**	$h_3 = a_1$
A4	**LOCAL**	**LOCAL**	$h_4 = a_1 + b_1$
A5	**LOCAL**	**REMOTE**	$h_5 = a_1 + b_2$
A6	**REMOTE**	**HOME**	$h_6 = a_2$
A7	**REMOTE**	**LOCAL**	$h_7 = a_2 + b_1$
A8	**REMOTE**	**REMOTE**	$h_8 = a_2 + b_2$

Table 1: SU Locations after the n^{th} and the $(n+1)^{th}$ Handovers

in the analytical results presented later in this section.

Signaling delays between the SU and the new and old serving RSs are constants independent from the location of the SU. Besides, since the SU communicates with the serving RSs through direct wireless links (without going through intermediate switches), the communication delay is relatively small. We will estimate the handover delay by the sum of the signaling delays between the anchor RA and the new and old serving RAs. When necessary, the signaling delay between the SU and the serving RSs can be taken into account simply by adding the constant delay value to the estimated handover delay obtained. The last column of Table 1 gives the handover delay for each of the eight handover types.

We assume $r_i(n+1)$ to be the probability that the n^{th} and the $(n+1)^{th}$ movements after the call arrival belong to combination **A**i $(1 \leq i \leq 8)$ as given in Table 1. The derivation of $r_j(n)$ $(1 \leq j \leq 8)$ can be found in Appendix B of [4]. The expected handover delay during the SU's stay in state i (between the instants that the transition into and the transition out of state i occur) of the Embedded Markov chain is

$$d(i) = \sum_{k=1}^{8} r_k(i+1)h_k \tag{5}$$

The *expected handover delay* can be obtained as

$$D = \sum_{k=0}^{\infty} p_k d(k) = \rho \sum_{k=0}^{\infty} (1-\rho)^k d(k) \tag{6}$$

4.2 Analytical Results

For the analytical results given in this section, we assume that the RA residence time, t_m, follows the Gamma distribution with mean $\frac{1}{\lambda_m}$ such that

$$f_m^*(s) = \left(\frac{\gamma\lambda_m}{s+\gamma\lambda_m}\right)^{\gamma} \tag{7}$$

Set	a_1	a_2	b_1	b_2
1	1	10	1	10
2	1	5	1	5
3	1	2	1	2
4	1	5	2	10
5	2	10	1	5

Table 2: Cost Parameters

where γ is the shaping parameter. The expression of ρ is

$$\rho = 1 - \left(\frac{\gamma\lambda_m}{\lambda_c + \gamma\lambda_m}\right)^{\gamma} \tag{8}$$

The Gamma distribution encompasses a family of probability distributions. It can be used to model the Exponential, the Erlang, and the Chi-square distributions by using the appropriate parameter values. The Gamma distribution also allows us to approximately model measured data distributions by fine-tuning the parameters. In the following, we will first demonstrate the handover delay under various mobility, call duration and signaling delay parameters. We will then study the effect of RA residence time variance on the performance of the handover method by using difference γ values.

4.2.1 Handover Delay Analysis

In this section, we evaluate the handover delay by setting $\gamma = 1$ such that the RA residence time, t_m, follows the exponential distribution. The expression of ρ is simplified to

$$\rho = \frac{\lambda_c}{\lambda_c + \lambda_m} \tag{9}$$

The performance of the anchor RS handover method under different values of γ is considered in Section 4.2.2.

For the analytical results given in this section, we assume the size of an SA, $k \times k$, is 64. Here we define the *call-to-mobility* ratio (CMR) to be the fraction $\frac{\lambda_c}{\lambda_m}$. In the following analysis, we consider CMR values from 0.01 to 100. Instead of fixing the signaling delay parameters, a_1, a_2, b_1 and b_2, to predefined constants, we consider five sets of signaling delay parameters (as given in Table 2) which encompass a wide range of signaling delay characteristics. Each set of signaling delay parameters given in Table 2 is normalized to the parameter that has the smallest value (such that the parameter with the smallest value is always equal to 1). Parameter set 1 captures the situation when the delay of a handover within the anchor SA is significantly lower than that of a handover outside of the anchor SA. Parameter sets 2 and 3 capture the situations when the delay for a handover within the SA is closer to that of a handover outside the anchor SA as compared to parameter set 1. For the first three parameter sets, 1, 2 and 3, we assume that the signaling delay between the anchor RS and the new serving RS is the same as that between the anchor RS and the old serving RS. Parameter sets 4 and 5 consider the cases when the signaling delay between the anchor RS and the new serving RS is different from that between the anchor RS and the old serving RS. The parameter values described above are selected to simplify our analysis. Other values for the SA size, the CMR and the signaling delay can be considered using the analytical model as discussed in Section 4.1.

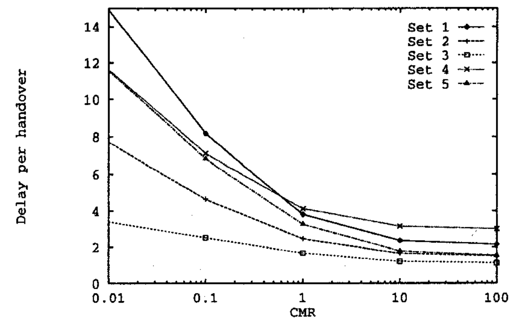


Figure 10: Handover Delay Under Exponential RA Residence Time Distribution

Figure 10 shows the handover delay under different CMR values for the five sets of signaling delay parameters given in Table 2. In general, the handover delay decreases as the CMR increases. When the CMR is small, such as 0.01, the duration of a call is significantly longer than the inter-handover interval. As the anchor RS is changed only when a call is established, the distance between the anchor RS and the SU is large when CMR is small. As a results, most of the handovers are performed outside of the anchor SA and the expected handover delay is, therefore, high. When the CMR is large, such as 100, the call duration is significantly shorter than the inter-handover interval. As the anchor RS is changed frequently, the SU stays at its anchor SA most of the time. This results in low expected handover delay.

The results for parameter sets 1, 2, and 3 are intuitive. The handover delay increases with the CMR, as described above, and the handover delay is high when the signaling delays are large. The results for parameter sets 4 and 5 demonstrate that, when the CMR is large, an increase in the signaling delay between the anchor RS and the new serving RS (b_1 and b_2) results in a higher increase of handover delay as compared to a similar increase in the signaling delay between the anchor RS and the old serving RS (a_1 and a_2). This is true because when the CMR is large, the call duration is short and most of the handovers belongs to type **A1** which has a delay $h_1 = b_1$. As a result, an increase in b_1 will result in a corresponding increase in the handover delay while an increase in a_1 has limited effect.

4.2.2 Effect of RA Residence Time Variance

Here we study the effect of RA residence time variance on the performance of the Anchor RS handover method. The Laplace transform of the Gamma density function is given by Equation (7) and the expression for ρ is given by Equation (8). Since the variance of Gamma distribution is $\frac{1}{\gamma\lambda_m^2}$, we can adjust the variance by varying the value of γ while fixing the mean RA residence time to $\frac{1}{\lambda_m}$. A small value of γ results in high variance and vice versa.

Figure 11 shows the effect of RA residence time variance on handover delay using parameter set 1 as given in Table 2. Parameter set 1 is selected as it produces a large range of handover delay values (from 2 to 15) when the CMR is varied (as shown in Figure 10). We are interested in finding out whether the handover delay will be affected if different RA residence time variances are used. We consider five values of γ, 0.01, 0.1, 1, 10 and 100, for this analysis and the result is given in Figure 11. It is demonstrated that, when CMR is low, the effect of γ on the handover delay is minimal. As the value of CMR increases, the handover delay is higher when the value of γ is smaller.

A large γ value results in small RA residence time variance and the inter-handover interval is always close to the mean value $\frac{1}{\lambda_m}$. On the other hand, a small γ value results in large RA residence time variance and the inter-handover interval may deviate significantly from the mean value. For large CMR, the call duration is relative short and most of the handovers are of type **A1** which has a relatively low signaling delay. Under this situation, an inter-handover interval which is longer than the mean value will not have significant effect on the handover delay. However, an inter-handover interval which is significantly shorter than the mean value increases the distance of the SU from the anchor RS which, in turn, results in an increase in delay for subsequent handovers. Consequently, the handover delay is high when the RA residence time variance is large and the CMR is high.

5 Conclusion

This paper introduces an analysis of a new handover method, known as the Anchor Radio System (RS) method, for the Personal Access Communications System (PACS). This technique performs the inter-RS handover and inter-switch handover. This method of handover relies on a new RS-to-RS interface, referred to in this paper as the Inter-RS Interface (IRI). This paper describes the use of the IRI Protocol (IRIP) in PACS-based RSs. This anchor RS handover method provides a simple yet effective solution without adding new requirements to the existing network infrastructures.

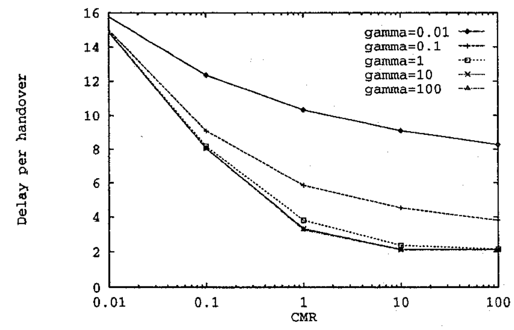


Figure 11: Handover Delay Gamma RA Residence Time Distribution

This paper introduced an analytical model for the Anchor RS handover method. We first developed an Embedded Markov chain model that captures the mobility and calling pattern of a subscriber unit (SU). The expression for the expected handover delay is then derived given the mobility, call duration and signaling delay parameters. This analytical model allows us to compare the performance of the Anchor RS handover method to other available handover schemes such as switch-based handover. Because of space limitation, detail results on performance comparison will be reported in an extended version of this paper.

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