A Pattern Language for Radio Resource Management

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Abstract. In a mobile wireless communication environment, the network controls the provision of a dedicated channel to the mobile station over the radio interface. The main concern of the network is how to maintain this dedicated channel despite the wanderings of the users. This paper documents a pattern language related to radio resource management functions. These patterns are suitable to be reused at the requirements and analysis stages of the development process and evolution of mobile systems. In addition, we show the integration of the pattern language for mobility management presented in [3] with the patterns for radio resource management.

1 Introduction

This paper presents a set of patterns related to radio resource management functions. As mentioned in [3], which describes a pattern language for mobility management, we identify commonalities among the following second and third generation mobile systems: Global System for Mobile Communications (GSM) and General Packet Radio Services (GPRS) [8][24][27], American National Standard Institute 41 (ANSI-41) [6][15], Wireless Intelligent Network (WIN) [13], Universal Mobile Telecommunications System (UMTS) [8], International Mobile Telecommunication Systems 2000 (IMT-2000) [19][20][21], and Wireless mobile ATM (WmATM) [7].

Radio resource management functions handle the connection, which is done through radio access ports (known as air interface), among base station transceivers (BSTs), base station controllers (BSCs), and mobile stations (MSs). MS is an equipment used to terminate the radio path at the user side. At the network side, mobile switching centers (MSCs) are also involved. MSC constitutes the interface for user traffic between the cellular network and other public switched networks, or other MSCs in the same or other cellular networks.

As depicted in Figure 1, a mobile system environment is split into cells. A cell is the region covered by the radio signal of a base station transceiver that supports the radio resource management functions related to the use of the allocated spectrum. Adjacent cells use different frequencies so that they do not interfere. However, a radio frequency can be reused in cells that are further away. Since many mobile stations can share the capacity of a base station transceiver, as the density of mobile stations in an area increases, the strength of the radio signal decreases. More base station transceivers are then deployed in the same area. This allows the same frequencies to be reused more often increasing the total capacity of the system. In this context, large cells are usually applied to remote areas and small cells for high-density traffic areas. In addition, radio engineers design cells with a variety of shapes (e.g., circular or sectored cells) [27].

A base station controller is responsible for monitoring a certain number of cells grouped in a location area. The set of BST and BSC is often referred to as base station (BS). In this paper, one or more base station controllers can be responsible for a location area; however, a single mobile switching center manages each location area. Figure 1 illustrates a mobile station (represented by a car) moving from its home location area to a different location area (called visitor location area). The handoff (also known as handover in Europe) procedure guarantees the quality of the connection (i.e., the dedicated radio channel between the mobile station and the network) that allows each mobile user to roam.

Handoff is a critical functionality for mobile systems since all communication services should be provided while the user is roaming. Without handoffs, calls are dropped as soon as the user moves far from the base station of the home location area. We capture and document patterns on the basis of the architectural elements and their functional behaviors related to handoffs, which constitute the main problem for the radio resource management. As depicted in the figure, handoffs can occur in three different ways regarding which network equipment is involved [17][19][24].

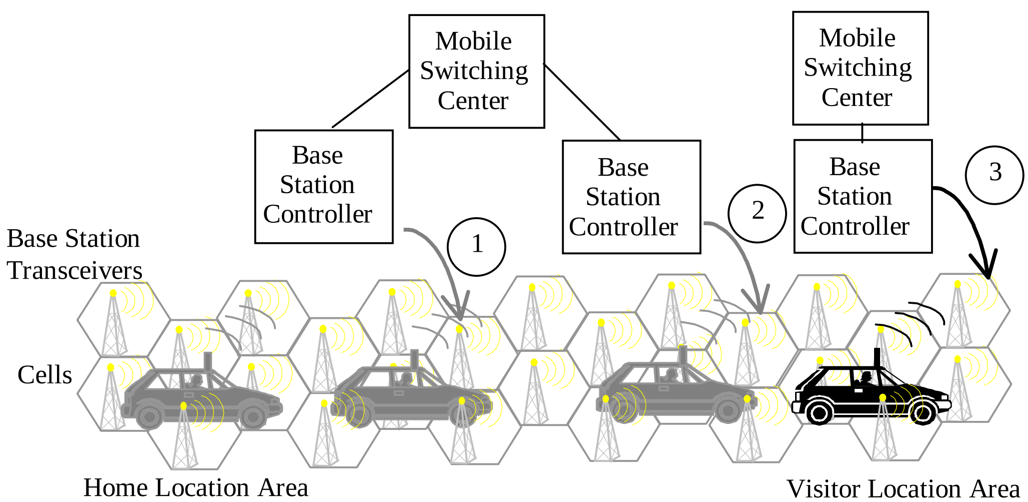

Figure 1. Type of Handoffs

Inter-base station transceiver handoff involves modifications only in the radio channel between base station transceivers and the mobile station (position 1 in the figure). *Inter-base station controller* (or intra-mobile switching center) handoff includes also changes in the base station controllers (position 2). These types of handoffs are also known as intra-system handoff. Finally, the *inter-mobile switching center* handoff (also known as inter-system handoff) involves different mobile switching centers (position 3).

As illustrated in the figure, base station transceivers and base station controllers are important components of the handoff process; however, this work considers only the handoff that generates network traffic, which involves different mobile switching centers. Thus, we focus on the inter-system handoff. At the upper layers, the inter-system handoff is managed by mobile stations and mobile switching centers. Base station transceivers and base station controllers act as complex transmission systems. This handoff requires specialized signaling protocols between the current and the candidate mobile switching centers that are involved in the process.

At a high level of abstraction, mobile systems contain a set of functional entities that are incorporated into network entities at a low level of abstraction. Network entities are then mapped to the real physical entities at the implementation level. As mentioned earlier, several common architectural (or structural) elements, which are used as a synonym for functional entities and network entities in this work, are identified among mobile systems [8][17]. The next sections mentions the following common architectural elements: mobile station, mobile switching center, base station transceiver, base station controller, and databases such as home location register and visitor location register.

This paper is organized as follows. The next section presents a pattern language that shows the relationship between the patterns related to radio resource management. These patterns are detailed in Section 3. Section 4 introduces the integration of the pattern language for mobility management introduced in [3] with the patterns for radio resource management. Conclusions are addressed in Section 5 and a summary of the radio resource management patterns is provided in the Appendix.

2 The Pattern Language for Radio Resource Management

After investigating radio resource management concerns of the mobile systems mentioned in the last section, we identify the following patterns: *handoff decision* (Section 3.1), *anchor mobile switching center* (Section 3.2), *inter-system handoff execution* (Section 3.3), *handoff failure actions* (Section 3.4), and *releasing resources* (Section 3.5). A handoff decision is taken every time is appropriate to change a radio communication link. The execution of an inter-system handoff maintains the stability of the dedicated radio channel despite the user's movement to another location area (e.g., visitor location area in Figure 1). An anchor mobile switching center handles the resources for the exchanges of information during the inter-system handoff process. The network is also responsible for handling unsuccessful outcomes during the inter-system handoff execution. The use of radio resources is minimized by releasing circuits that are no longer necessary when a user roams.

These patterns are grouped in a pattern language that shows their relationships as depicted in Figure 2. The pattern language for radio resource management follows the same layout used in [3] for illustrating the pattern language for mobility management: ovals represent patterns extracted from functional behaviors called *behavioral patterns*, rectangles represent patterns captured from architectural elements called *structural patterns* and plain and dashed black arrows illustrate the relationship among the patterns.

Plain arrows describe possible sequences that a designer can follow when reusing the patterns. For example, the gray arrow with the roaming label depicts a possible start point for a scenario that is derived from the pattern language as follows. Whenever a user moves from one location to another, the *handoff decision* monitors the quality of the link between the mobile station and the network. If an inter-system handoff is necessary, the *inter-system handoff execution* guarantees communication services to the user. Unsuccessful handoff outcomes can also occur in this case and *handoff failure actions* handle them. After successful or unsuccessful handoffs, *releasing resources* are supported by the network.

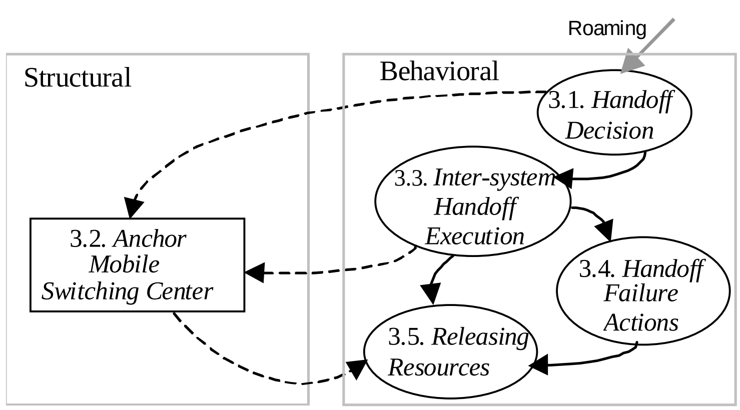

Figure 2. A Pattern Language for Radio Resource Management

Dashed arrows represent the exchange of requests for control or release of resources between the patterns. For instance, the *handoff decision* sends a request to the *anchor mobile switching center*, which controls the use of resources (e.g., *releasing resources*). An *inter-system handoff execution* also requests to the anchor mobile switching center that unnecessary radio resources are released.

These patterns are suitable to be reused at the requirements and analysis stages of the mobile system development process and evolution. We apply a technique called Use Case Maps (UCMs) [11] to graphically specify possible scenarios for each pattern solution. UCMs shows general responsibilities and general control flows between these responsibilities for the pattern solutions. We choose the UCM notation for its flexibility that allows the description of the functional behaviour and the architectural elements independently and then the mapping between them.

At the requirements capture stage, UCMs are called *unbound* since they combine paths and responsibilities without defining system components. At the analysis and design stages, *bound* maps describe how the architectural structure and the system behavior are related. The UCMs introduced in the pattern solutions are all bound. Note there the salient elements of the UCM notation: start points denoted by filled circles, abstract responsibilities denoted by crosses, choice points denoted by forks in a path (OR forks), and end points denoted by bars. Abstract responsibilities can be refined in many ways at further stages of design. For a more detailed description of the UCM notation, the reader may refer to [11].

3 Patterns related to Functional Behaviors and Architectural Elements

3.1 Handoff Decision

Context

A dedicated radio communication channel has been assigned between a mobile station, which has changed from the idle to the dedicated mode, and a mobile switching center for transmitting signaling and data. The mobile user is roaming from one place to another. This possibility of changing cells (and possibly location area) is the major source of complexity for mobile networks [15][24].

Problem

How do you monitor the quality of the radio communication link between the mobile station and the network?

Forces

- The radio communication is interrupted as soon as the user leaves the radio coverage area of the current cell whether a call is in progress or not;

- When a call is in progress, the radio communication cut-off has an important weight in the overall perception of quality from the user's point of view;

- When comparing the capability of two cells, the load of each base station transceiver and the overall interference level in each cell affect the radio link quality;

- Local geographic peaks can occur in events such as sport competitions, concerts, and festivals. It is possible in these situations that a cell is congested in the peak area while its neighbor cells are not.

Solution

Take measurements on the quality of the transmission for ongoing dedicated radio connections, check the transmission quality on the neighbor cells, and verify the load of the base station transceiver. Then, decide whether a handoff should be triggered or not. This decision is based on the received signal measurements concerning the current cell and when it is necessary, the neighbor cells.

These measurements are best taken by the current base station or both the current base station and the mobile station with parameters, such as: transmission error rate, the propagation path loss, the propagation delay, traffic considerations, as well as the cell capacity and load. Mobile stations provide measurements of the received base station signal strength to the current mobile switching center. Adjacent base stations also provide measurements to the current mobile switching center while the mobile station moves towards their coverage areas.

The handoff decision can be taken by the mobile station (MS-controlled handoff), the serving MSC (network-controlled handoff) or both (MS-assisted handoff - MAHO) depending on implementation issues. When the handoff involves two radio channels that are controlled by the same MSC (intra-system handoff), the base station controller can also take the handoff decision.

Figure 3 shows a handoff decision involving two or more mobile switching centers (MSCs) (inter-system handoff). The current MSC queries adjacent MSCs to determine whether the mobile station should be relocated to another MSC. The adjacent MSCs send handoff measurements, which contain the radio signal strength that is being received on the specific channel. The current MSC examines each measurement to determine whether a handoff is appropriate or not.

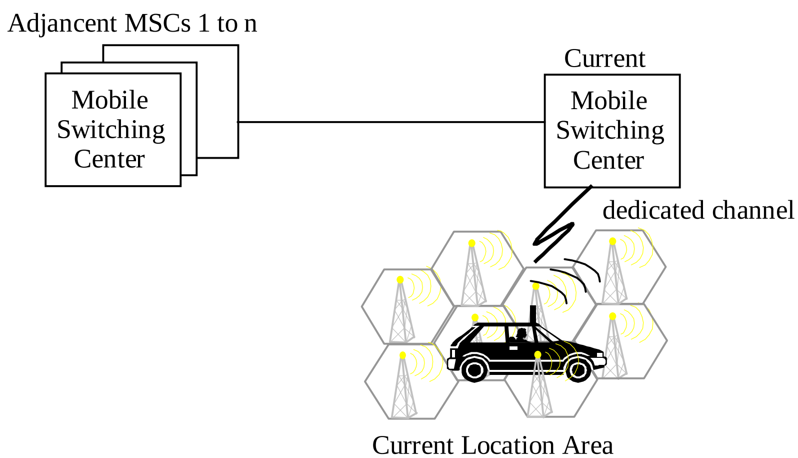

Figure 3. *Handoff Decision* with different MSCs

Figure 4 depicts a possible scenario for applying a *handoff decision*. The map starts when the user moves to another location area .The *handoff decision* is taken according to the measurements (e.g., crosses represent UCM responsibilities). In this scenario, a mobile switching center receives the measurements and decides whether the handoff is necessary or not. The alternative paths (called Or-forks) represent UCMs that can be split into two different paths. For instance, [handoff is necessary] and [no handoff is necessary] paths represent the need of having a handoff or not. Bars are UCM end points.

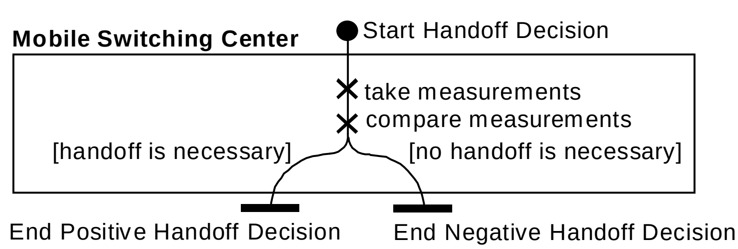

Figure 4. A Scenario for the *Handoff Decision* with bound UCMs

Known Uses

The handoff decisions taken by the signaling alternatives for WmATM presented in [7], the ANSI-41 Handoff Measurement Request scenario presented in [15], and GSM based systems such as GSM-900 and GSM-1800 [8][24] follow this pattern.

Resulting Context

After the decision about the need of a handoff, an intra-system or an *inter-system handoff* (Section 3.3) can occur. Otherwise, there is no need for handing off. An *anchor mobile switching center* (Section 3.2) handles the network resources without being perceived by the mobile user.

3.2 Anchor Mobile Switching Center

Context

A *handoff decision* (Section 3.1) has been taken and an inter-system handoff, which involves the modification of a dedicated transmission path between a mobile station and a mobile switching center, should be performed [8][24].

Problem

How do you manage the network resources involved in information exchanges during an inter-system handoff?

Forces

- The physical transmission path, which includes both the dedicated radio channel between the mobile station and the network and the fixed transmission path within the network, is constantly modified by handoffs;

- If the transmission path is released as soon as an inter-system handoff decision is taken, all call information that should be transmitted to the new mobile switching center is completely destroyed. This can happen regardless whether a new channel is allocated successfully or not;

- Charging is complicated with more than one mobile switching center responsible for a call from the beginning to the end.

Solution

Choose the first mobile switching center that is serving the mobile station when the dedicated channel is allocated to be in charge of the communication. This anchor mobile switching center keeps control of the call processing information including the billing record during the inter-system handoff. Figure 5 depicts an example of an anchor MSC.

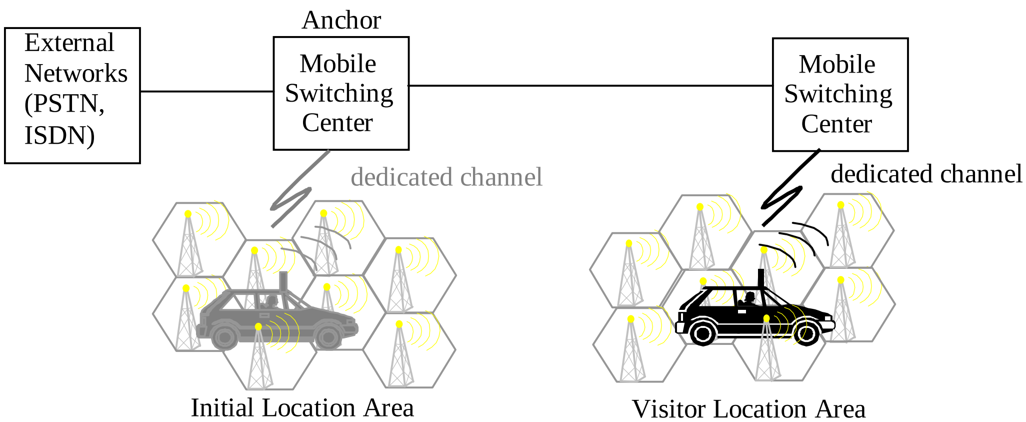

Figure 5. ANSI-41 Successful Handoff-Forward with *Anchor MSC* [6]

When an inter-system handoff occurs, the network configuration changes and other mobile switching centers become involved. The anchor remains the same and these centers become just relays. When the anchor mobile switching center is different from the previous mobile switching center, the following example shows its use: if the quality of the new channel is worse than the previous one, the anchor requests the previous base station controller to re-direct the transmission to the previous mobile switching center.

Figure 7, Figure 8, and Figure 10 illustrate scenarios that contain an *anchor mobile switching center* as a component. These scenarios describe *inter-system handoff execution, handoff failure actions and releasing resources* with bound UCMs.

Resulting Context

The *anchor mobile switching center* is responsible for controlling the resources that guarantees the signaling and data information exchanges during inter-system handoffs. The handoff process includes *inter-system handoff execution* (Section 3.3) and eventually *handoff failure actions* (Section 3.4)

When a *location registration* (see [3] and Section 4) occurs in consequence of a handoff, the *anchor mobile switching center* is also in charge of the resources for the information exchanges.

Known Uses

Anchor Mobile Switching Center is used in ANSI-41 Specifications (see Figure 5), GSM, and GPRS based systems (called anchor MSC).

3.3 Inter-system Handoff Execution

Context

A *handoff decision* (Section 3.1) has been taken and it is necessary to perform a handoff that involves different mobile switching centers as depicted in Figure 6. An *anchor mobile switching center* (Section 3.2) has been chosen to control the resources for the information exchanges.

Problem

How do you continuously guarantee communication service assessment for mobile users?

Forces

- Communication services, which the user have been assessing, can be cut off as a result of:
  - the candidate mobile switching center (MSC) does not support the requested radio channel characteristics. For example, a TDMA digital channel is required but not available;
  - the signal quality of the candidate MSC is below an acceptable threshold;
  - the current traffic conditions on the candidate MSC does not allow handoff traffic at a given time;
- Users' expectations are not met without reliability and consistency of the signaling and data transmission.

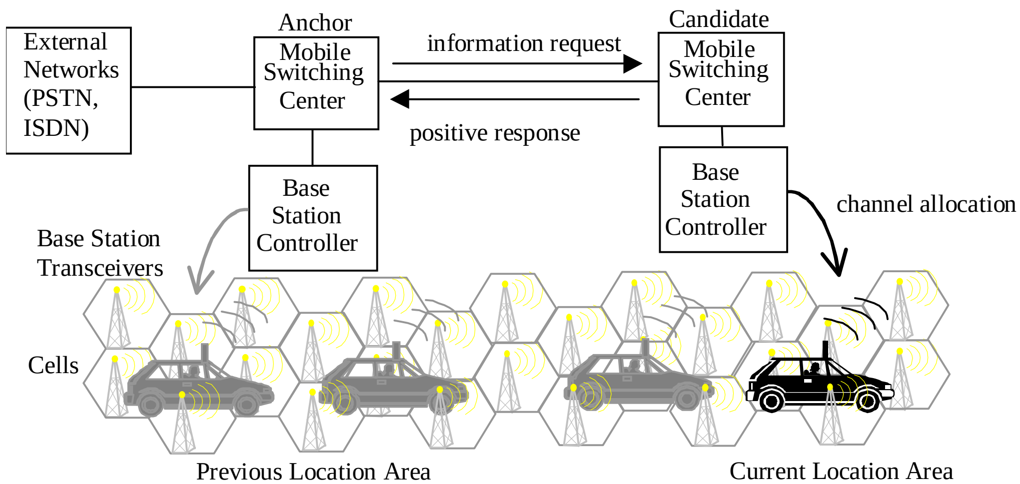

Figure 6. A successful Inter-system Handoff

Solution

Identify the candidate MSC, which is considered for handoff purposes, and evaluate its reliability before executing the handoff. Then, the candidate mobile switching center is selected to handle the communication. After this, it allocates a new channel to provide communication services, detects and accepts the mobile station in its location area. Then, the mobile station tunes to the new channel. According to the communication status (whether a communication between two users is occurring or not), the call is also rerouted.

Figure 7 depicts a possible scenario for performing an inter-system handoff. The scenario starts with a triggering event request, which represents the positive *handoff decision* (see end points in Figure 4). After this, the candidate MSC is evaluated to guarantee that the new link has better quality of transmission than the previous one. If the evaluation is positive, a new channel is allocated and the mobile station tunes to the new channel (successful outcome). Otherwise, an unsuccessful sub-path is generated as a result of this action (see Figure 8).

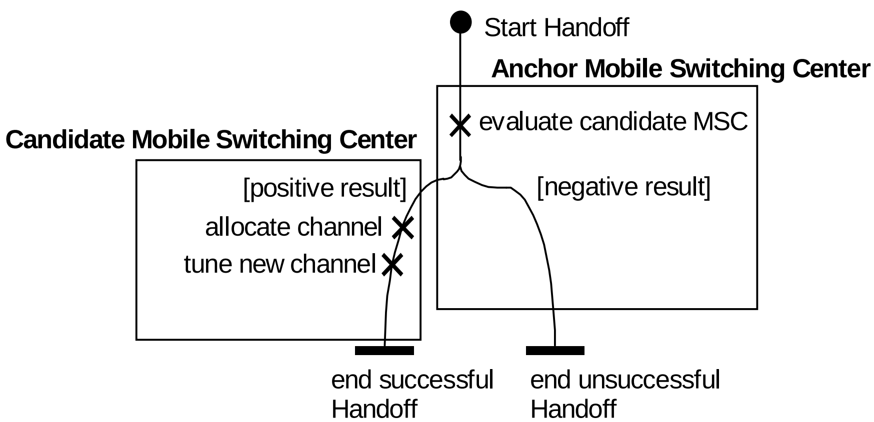

Figure 7. A scenario for the *Inter-System Handoff Execution* with bound UCMs

Resulting Context

The *inter-system handoff execution* has been successfully performed and the mobile station characteristics are stable. The *anchor mobile switching center* (Section 3.2) is then able to release the resources that are no longer needed (*releasing resources* in Section 3.5). Meanwhile, *home and visitor databases* (see [3] and Section 4) update mobile user's location information. This successful outcome is transparent to the user.

On the other hand, when an unsuccessful outcome occurs during this process, the network takes *handoff failure actions* (Section 3.4).

Known Uses

Inter-System Handoff Execution is used in ANSI-41 Specifications, GSM/GPRS specifications, and WmATM networks. For instance, the handoff is performed through previous or candidate ports in case of WmATM. ANSI-41 documents also present different successful and unsuccessful scenarios for handoff back and forward.

3.4 Handoff Failure Actions

Context

A failure has occurred during the *inter-system handoff execution* (Section 3.3) due to the lack of radio or terrestrial resources in the candidate mobile switching center or an unexpected propagation loss (for example, obstacles such as bridges or tunnels) during the channel allocation. As mentioned earlier, an *anchor mobile switching center* (Section 3.2) controls the allocated resources during inter-system handoffs when the mobile station is in dedicated mode.

Problem

How does the network handle an inter-system handoff failure?

Forces

- The *handoff decision* (Section 3.1) and the *inter-system handoff execution* reduce the chances of a handoff failure. However, a failure is not suppressed completely and the communication with the current cell can be effectively lost;

- The current communication service, which the user has been assessing, is cut off with possibly loss of information. This failure can be perceived by the user;

- Before the failure has occurred, several communication resources could have been allocated including the transmission path;

Solution

Choose one of the following alternatives: a new handoff attempt towards the same cell, a new handoff attempt towards another cell, or tunes to the previous channel (see Figure 8). Then, request the release of all the previously allocated resources (*releasing resources* in Section 3.5) along the path in which the failure has occurred. One alternative that should be avoided is to lose the communication between two users or the ability to access network services. The *anchor mobile switching center* (Section 3.2) chooses one of the previous alternatives.

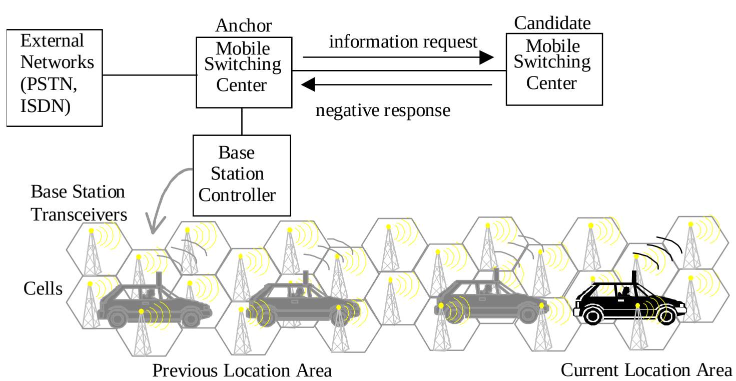

Figure 8. An unsuccessful Inter-system Handoff

Figure 8 depicts a generic solution for performing *handoff failure actions*. The anchor mobile switching center requests the mobile station to attempt a new handoff to another cell ([another cell] path), to tune to the previous channel, or to attempt another handoff to the same cell ([same cell] path). Then, the scenario for *Releasing resources* shown in Figure 10 should be performed after that.

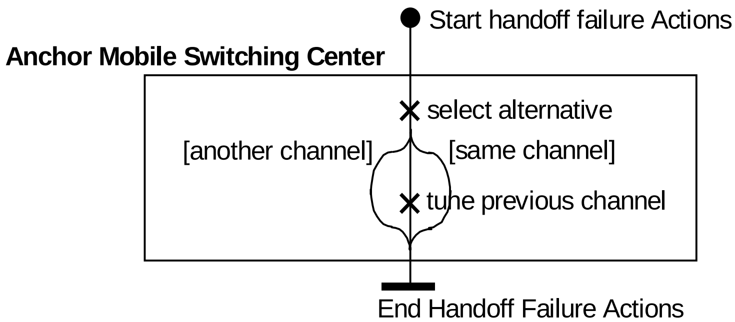

Figure 9. A Scenario for *Handoff Failure Actions* with bound UCMs

Resulting Context

Either a handoff has been re-initiated (first and second alternatives) or the mobile station has tuned to the previous channel (the last alternative). Furthermore, all the resources in use during the failed handoff have been de-allocated (see *releasing resources*).

Known Uses

All *handoff failure actions* are used in ANSI-41 Specifications, GSM/GPRS, and WmATM networks. Third generation systems such as IMT-2000 Systems and UMTS take only two actions: new handoff attempts to another cell or to the same cell.

3.5 Releasing Resources

Context

An *inter-system handoff execution* (Sections 3.3) has successfully occurred or *handoff failure actions* (Section 3.4) have been taken. Meanwhile, the *anchor mobile switching center* (Section 3.2) is controlling the allocated resources despite handoffs.

Problem

How does the network minimize the use of resources that are no longer needed, such as the inter-mobile switching center circuits?

Forces

- Besides the amount of inter-mobile switching center circuits available being limited, these resources are necessary not only for handoff execution, but also for location registration;

- If the user is out of coverage, or has powered off the mobile station in the middle of a call, the network infrastructure has to detect that the resources are no longer needed and make sure that the mobile station is back to the idle mode;

- Before a mobile station is back to the idle mode (after finishing a call or due to a network failure), a frame loss can occur and the mobile station can still transmit on its dedicated channel while the network is allocating the same channel to another mobile station.

Solution

Release the unnecessary inter-mobile switching center circuits using a request from the *anchor mobile switching center* (Section 3.2) to the previous mobile switching centers involved in the handoff (see Figure 10). In order to avoid conflict on the allocation of channels, the mobile station goes back to the idle mode or stops using the channels before the network releases the resources.

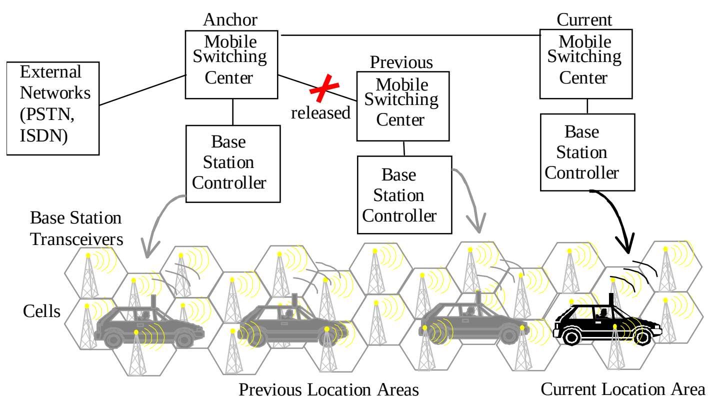

Figure 10. Releasing Resources after a successful Inter-system Handoff Execution

Figure 10 depicts a possible solution for *releasing resources*. This function is performed after either the *inter-system handoff execution* or the *handoff failure actions* patterns.

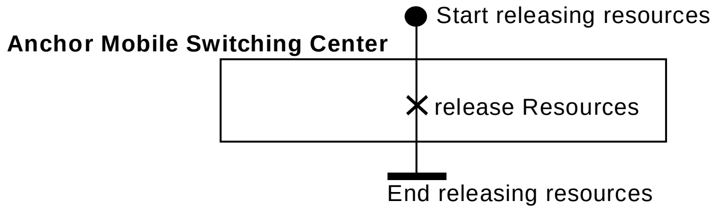

Figure 11. A Solution for Releasing Resources with bound UCMs

Resulting Context

Once the inter-mobile switching center circuits have been released, they are available for allocation to other purposes.

Known Uses

Resources are released by the signaling alternatives for WmATM networks. This pattern can be also found in the ANSI-41 Handoff and call release scenarios and in the GSM Handoff scenarios. *Releasing Resources* is also used in IMT-2000 Systems and UMTS.

4 MoRaR: A Pattern Language for Mobility and Radio Resource Management

Figure 12 depicts a pattern language called MoRaR that shows the integration of the patterns related to mobility management presented in [3] and the patterns related to radio resource management. The behavioral and structural patterns mentioned earlier are classified into two categories (dashed rectangles) as follows: mobility management and radio resource management.

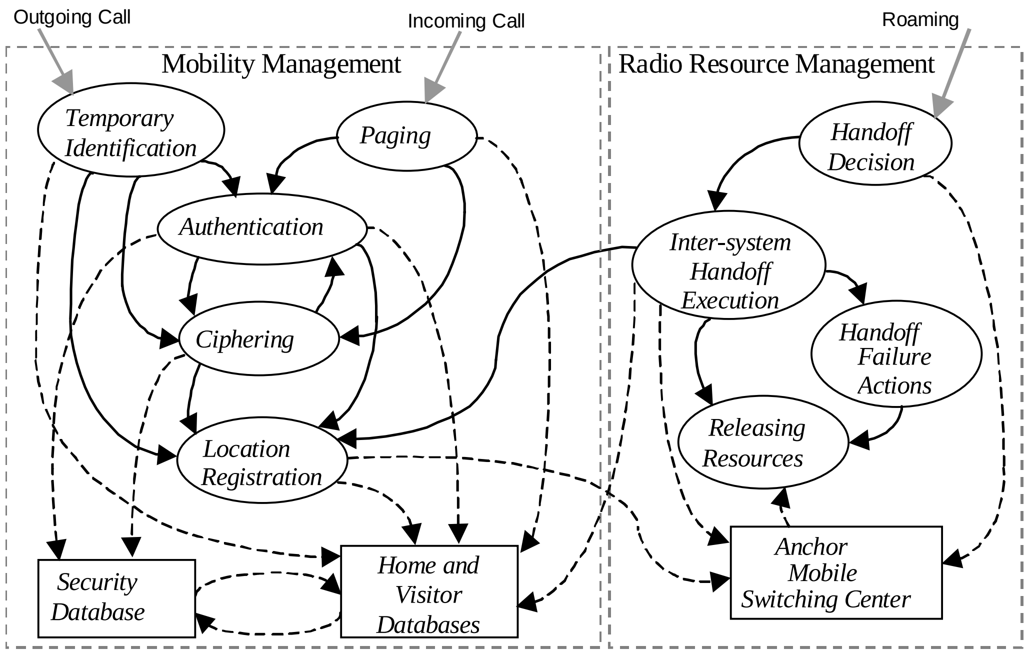

Figure 12. Relationship among the Patterns within the MoRaR Pattern Language

This pattern language facilitates a concise description of mobility and radio resource management functions suitable to be adapted to different mobile systems at the requirements and analysis stages. Designers are then able to find the patterns that are relevant for what they intend to do and generate different scenarios at the early stages of the development process and evolution of mobile systems.

5 Conclusion

This paper presents a pattern language for radio resource management functions. As presented in [3], these patterns are extracted from the common solutions used in the following mobile wireless communication systems: GSM/GPRS/UMTS [24], ANSI-41 [2][6][15], IMT-2000 [19][20][21][25], and WmATM [7][13][29].

In addition, a pattern language called MoRaR gathers the mobility management patterns shown in [3] and the radio resource management patterns presented in this paper. These patterns are general and abstract enough to allow freedom with respect to future implementation decisions and to be re-used at the early stages of the system development process and evolution of mobile systems.

This work does not intend to cover all common functional behaviors and architectural elements among mobile wireless communication systems. We believe that common functionalities for communication management can be further investigated and patterns can be extracted from these commonalities. These patterns can be included in the MoRaR pattern language within a new category called communication management.

In addition, we believe that a more complete identification of the intersection between the software patterns presented in [29] and the requirements and analysis patterns documented in the MoRaR pattern language should be done. An attempt to do this is presented in the related patterns of the behavioral patterns (see details in [3]). This identification can help to migrate from the requirements and analysis models to object-oriented design and implementation.

6 Acknowledgments

Many thanks go to our PloP'2001 shepherd, Dennis DeBruler, for his insightful and valuable comments. We would like to thank Jim Coplien as well for encouraging us to be involved in the PLoP conferences. Finally, we acknowledge CAPES, CITO, and NSERG for their financial support.

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Appendix

The following table summarizes the patterns for radio resource management presented earlier. For more information about each pattern solution, the reader should refer to the respective sections.

Section	Problem	Solution	Pattern Name
3.1	How do you monitor the quality of the radio communication link between the mobile station and the network?	Take measurements on the quality of the transmission for ongoing dedicated radio connections, check the transmission quality on the neighbor cells, and verify the load of the base station transceiver.	*Handoff Decision*
3.2	How do you manage the network resources involved in information exchanges during an inter-system handoff?	Choose the first mobile switching center that is serving the mobile station when the dedicated channel is allocated to be in charge of the communication.	*Anchor Mobile Switching Center*
3.3	How do you continuously guarantee communication service assessment for mobile users?	Identify the candidate MSC, which is considered for handoff purposes, and evaluate its reliability before executing the handoff.	*Inter-system handoff execution*
3.4	How does the network handle an inter-system handoff failure?	Choose one of the following alternatives: a new handoff attempt towards the same cell, a new handoff attempt towards another cell, or tunes to the previous channel.	*Handoff Failure Actions*
3.5	How does the network minimize the use of resources that are no longer needed, such as the inter-mobile switching center circuits?	Release the unnecessary inter-mobile switching center circuits using a request from the *anchor mobile switching center* to the previous mobile switching centers involved in the handoff.	*Releasing Resources*

Table 1 Patterns related to Radio Resource Management