An Autonomic Connection Management Mechanism on Mobile Terminals*

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Abstract. This paper proposes an autonomic connection management mechanism for multi-homed mobile terminals. The knowledge repository and the case-based reasoning technique are used to enhance the autonomicity of the connection management. The multi-criteria handoff decision is the core of the mechanism. Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) are combined to make the handoff decision. Simulation results and performance analysis show that the proposed mechanism works well in the heterogeneous wireless access network environment.

Keywords: Vertical handoff, connection management, autonomicity.

1 Introduction

Multi-homed terminals, which have more than one network interface or global address, can have several parallel communication paths simultaneously through attaching to one or more access networks. In heterogeneous wireless and mobile environment, the multi-connection scenario [1] puts forward great challenges to the connection management.

In the multi-connection scenario, the connection management is responsible for selecting the most suitable network for each application's connection and achieving effective use of the integrated networks resources. In heterogeneous wireless and mobile environment, the seamless vertical handoff for each connection needs to be considered, which is very important for both the effective use of the integrated network resources and the performance of the applications.

There are several advantages for performing connection management on mobile terminals (MTs). On the one side, the MT can gather various handoff related information. On the other side, it helps to decrease the complexity in networks and is beneficial for network's scalability related issues. However, since the miscellaneous factors have

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* The work was supported by a grant from EU FP7 Project EFIPSANS (No, 215549) and Sino-Swedish Strategic Cooperative Programme on NGN (2008DFA12110).

[1] In this paper, a flow is a stream of packets from a source to a destination [1]; and a connection is regarded as a layer-3 logic path serving one flow of a particular application/service.

K. Pentikousis et al. (Eds.): MONAMI 2009, LNICST 32, pp. 41–48, 2010.

to be handled, MTs may spend extra processing time and memory for performing connection management.

To simplify the connection management and expedite the handoff decision, autonomicity [2] is introduced in the connection management mechanism in the MTs.

The rest of the paper is organized as follows. Section 2 gives an overview of related work in the area of mobility management. The basic principle of the autonomic connection management mechanism, along with a proposed handoff decision making algorithm based on AHP and SAW is described in section 3. In section 4, the performance of the proposed algorithm is analyzed according to the simulation results. Conclusion and future work are stated in section 5.

2 Related Work

Great efforts on vertical handoff related work have been made in recent years [3]-[11]. In general, they involved two categories of issues. One focuses on proposing certain handoff architectures for heterogeneous network environment, such as the USHA proposed in [3], the SIGMA put forward in [4], and the hierarchical mobility management architecture suggested in [5].

The other category focuses on suggesting some specific handover decision making algorithms or mechanisms, such as work in [6]-[11]. Among them, some traditional vertical handoff algorithms considered only the RSS or the data rate as the key handoff trigger event, such as [6] and [7], whereas others put more efforts on studying the multi-criteria handoff decision algorithms, such as [9]-[10]. However, both the algorithms in [8] and [9] are just suitable for application or service granularity, which are inadequate to handle finer granularity handoff decision, such as the connection-based handoff decision.

Several works have tried to implement intelligence of the proposed algorithm, such as [10] and [11]. In [10], the adaptive interface activating method adjusted the interface activating interval only according to the distance between the MT and the base station. In [11], pattern recognition was used to estimate the user's position, and the handoff decision was based on the obtained information. Both these algorithms have introduced intelligence to some extent, but neither of them really made decision based on multiple criteria.

Compared with the above algorithms, the proposed autonomic connection management mechanism in our paper has the following features: (1) AHP and SAW are combined to handle multi-criteria vertical handoff decision. (2) Furthermore, it is designed to achieve connection based handoff decision, and can realize more accurate handoff decision for each service flow. (3) Knowledge repository with self-learning function is adopted, which could bring autonomicity into connection management.

3 Autonomic Connection Management

In general, the connection management involves the following operations:

(ⅰ) Making handoff decisions for connections;

(ⅱ) Influencing or controlling some behaviors of an MT and the corresponding network nodes, such as base stations (BSs) or access points (APs), during handoff;

(ⅲ) Managing information of connections in an MT, stored in a CIL (Connection Information List). In our implementation, the CIL stores the identity and the corresponding information for all connections serving the applications in an MT. Each MT has a CIL, whose format is shown in Table 1.

Table 1. Format of a CIL

Connection Number	Connection Description
Con 1	(Status_Tag, Src.Uniq_ID, Dest.Uniq_ID, Flow_ID, Src.cur_IP, Dest.cur_IP, Service_Type)

In Table 1, each connection has one nonnegative integer as its identity, and can be identified by a five tuple: <Src.Uniq_ID, Dest.Uniq_ID, Flow_ID, Src.cur_IP, and Dest.cur_IP>. Here the Src.Uniq_ID and the Dest.Uniq_ID represent the unique identity for the source and the destination, respectively. Flow_ID is the identity of the flow served by the connection, which needs to be recognized by both the source and the destination. Src.cur_IP and Dest.cur_IP represent the current IP addresses used by the source and destination for the connection, respectively. Status_Tag with different values describes different status of connections. Service_Type represents the different service type. Information in the CIL needs to be updated or modified according to the changes of the environments.

3.1 Connection Management in MT

Connection management controlled by MTs is adopted in this paper. It is relatively easier for an MT to gather handoff related context information. Network status information could be measured by BSs and/or APs, and the results are sent to the MT. Other information, such as the application's requirement, user preference and device capability, can be collected by the MT itself. Using this mechanism, networks just assist the MT to do handoff decision and needs seldom changes on themselves.

3.2 Autonomic Connection Management

The connection management in our paper is an autonomic system, which has four steps forming a feedback loop as shown in Fig. 1. The system collects information from a variety of sources, which is analyzed to construct a case model of the evolving situation faced by the MT and its output by this model, i.e. certain a solution, is used as a basic

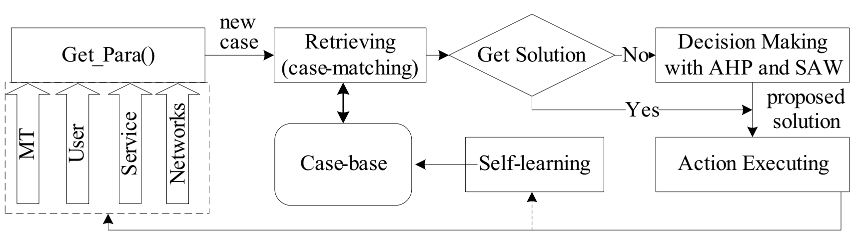

Fig. 1. Autonomic connection management

for intelligent decisions. The decisions are actuated through networks and MTs. The impact of decisions can then be collected to inform the next control cycle.

Step1 Context Collected by Get_Para()

Context information as follows needs to be collected for handoff trigger recognization, case matching in step 2 and multi-criteria handoff decision in step 3:

(ⅰ) *Network related factors*. The related factors of the networks where the MT roams to have to be collected, such as types of networks, availability of a network, limited available resources, their access mechanisms characteristics, etc.

(ⅱ) *Device related factors*. The capabilities of the MT include its battery life, processor speed, available interfaces. The MT's velocity is an important criterion.

(ⅲ) *Service requirement*. Wireless multimedia services can be classified into four service types, namely conversational service, streaming service, interactive services and background service [12]. Different types of services require various combinations of bandwidth, delay, jitter, reliability and cost.

(ⅳ) *User preference*. There are two criteria users are mainly concerned about, monetary cost and interface preference.

It is supposed here that the networks performance parameters can be acquired through the advertisement of the available access networks, or the MT can use data link layer probing or network layer probing. One result of Get_para() is a new case or problem description, which is used for the case matching in step 2.

Step2 Retrieving Similar Cases

Retrieving a case starts with a problem description and ends with whether a best matching case found or not. We adopt case based reasoning (CBR) techniques to implement the knowledge repository (KR). A case represents specific knowledge in a particular context. Case base is a cases library. Cases stored in the case base should be described clearly by "which service" using "which network" under "what conditions".

Table 2. Case description in CB

service type	velocity	network status	User preference	target network
Conversational,	x m/s	<Net1_para1,…,Net1_paraM>, ... <NetN_para1,…,NetN_paraM>	Pr_net1, ... Pr_netN	Net N

Case description is organized as Table 2. Each case has a vector description of service type, velocity, network status, user preference and target network.

Fuzzy matching is used to match the new case and cases stored in the CB. If a similar case is found, its solution can be directly reused to solve the current problem, going to step 4. If not, go to step 3 to generate a new solution.

Step3 Handoff Decision Making of A Multi-criteria Algorithm Based on AHP and SAW

A multi-criteria handoff decision making algorithm combining AHP and SAW will be described as follows.

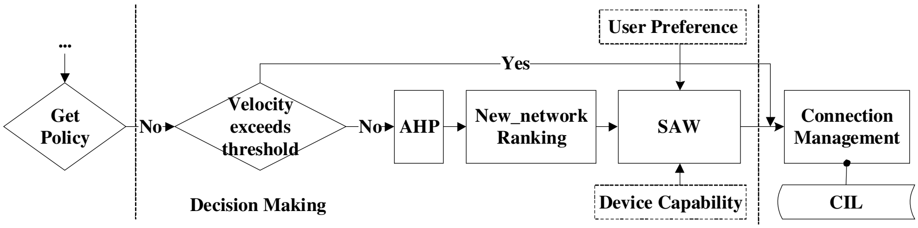

Fig. 2. Decision making with AHP and SAW

Step3.1 Velocity Judgment

As shown in Fig. 2, after all the necessary context information has been collected, the velocity of the MT is firstly analyzed to decide whether it is in the threshold scope. If it exceeds the threshold scope, just go to step 4. Nothing has to be done and CIL will be barely maintained. Otherwise, go to step 3.2.

Step3.2 Analytic Hierarchy Process (AHP) Based Network Ranking

AHP [13] is a well known and proven multi-criteria decision making approach to make the most appropriate choice among multiple alternatives based on some special goals. For AHP, all related factors are arranged in hierarchic structure, and paired comparisons in the same hierarchy are performed to generate priorities for criteria with respect to the predefined goal.

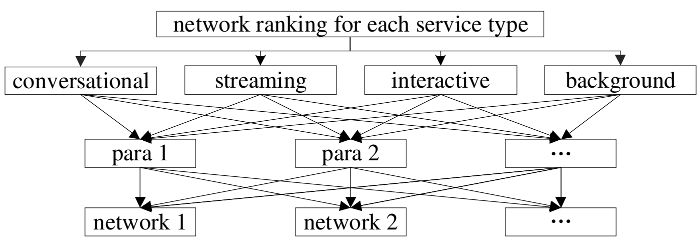

Fig. 3. Structure of the Analytic Hierarchy Process

Here AHP is used to get network ranking under the applications' requirements and the status of access networks. As shown in Fig. 3, the goal of "network ranking for each service type" locates in the first level. Four service types are in the second level. In the third level there are parameters that are considered with distinct importance by a factor in the upper level. Candidate networks reside in the fourth level.

Let's assume that parameters in the third level are bandwidth, delay, jitter, cost and reliability. Then we use the first four stages described in Section 3.2 of [8] to calculate new network ranking value for each service type, which is calculated by the equation (1), similar to equation (13) in [8].

$$R_{i\text{-}j} = \sum_k p_{i\text{-}k} * p_{k\text{-}j} \tag{1}$$

In (1), i, j, k represents a service type, a candicate network, some parameter in the third level, respectively. $p_{i\text{-}k}$ indicates the priority of parameter k among all parameters in the third level, for service type i. $p_{k\text{-}j}$ indicates the priority of network j among all available networks in the fourth level, for parameter k. Both $p_{i\text{-}k}$ and $p_{k\text{-}j}$ can be gotten by equation (9) in [9]. $R_{i\text{-}j}$ indicates the priority of network j among all networks, for service type i, and is always in the range of 0-1.

Step3.3Vertical Handoff Decision using SAW
After the network ranking for each service type is completed, handoff decision has to be made for each connection, which should take user preference and device capability into account. The priority of connection i in service type k W_{i-k} and the user preference $\Pr_{i-j}$ influences the final handoff decision Fo_{i-j} for connection i by (2).

$$Fo_{i-j} = W_{i-k} * R_{k-j} * \Pr_{i-j} \tag{2}$$

In (2), j represents the target network, and W_{i-k}, $\Pr_{i-j}$ are both in the range of 0-1. Similarly, the impact of device capabilities could be handled as above.

This multi-criteria algorithm takes advantages of both AHP and SAW to make handoff decision, whose performance will be analyzed in Section 4.

Step4 Action Executing
After the handoff decision for each connection gained from step 3, corresponding operations will be enforced on BSs/APs and the MT. With regard to BSs/APs, authorization for the MT to use their resources needs to be processed. For the MT, some connection entries in its CIL need to be modified.

The proposed solution is under observation. If the new case is well dealt with, the solution will be added to the CB. This is a self-learning procedure, a key step to achieve autonomicity in connection management. Along with more cases experienced by MT, the CB will get more plentiful. When the CB gets stable to some degree, new cases could be almost matched with cases in it and solutions can be directly retrieved rather than calculated by step 3.

4 Simulation Results and Performance Analyzing

Simulations were carried out in ns-2+802.21 [14] [15] to evaluate the performance of our mechanism. Fig. 4 illustrates the simulation scenario. Here it is supposed that the UMTS has full coverage while WLAN exists with access point located in (100,100), which has 50 meters coverage radius. The MT moves from (40, 100) to (160, 100) from 10s in the time axis with a certain constant velocity ($v_{\min} = 1m/s$,

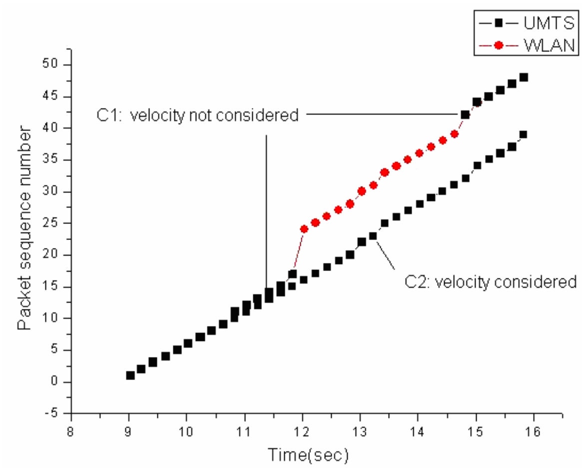

Fig. 4. Impact on packet loss rate of velocity

$v_{\max} = 30m/s$ and $v_{threshold} = 15m/s$). A correspondent terminal (CT) initiated a UDP connection with MT for data downloading, which last from 9s to 16s.

(i) Impact of MT's Velocity on Packet Loss Rate

Fig. 5 is an illustration of the packet loss rate under $v = 20m/s$, which has exceeded the threshold. As shown in Curve 1, if velocity was not considered, once WLAN was detected and a handoff decision that WLAN was more suitable for data downloading was made, a vertical handoff happened and the connection started to run in WLAN. When the MT moved out of the coverage of WLAN, the connection had another handoff and then run in UMTS again. During 9s and 16s, two handoffs happened. According to the data report in trace file, 15 packets were lost while 53 packets transmitted, so the packet loss rate was 0.28.

Relatively, velocity was taken into account for handoff decision in our mechanism. Since the velocity exceeded the threshold, whether the status of WLAN was better or not, the MT just kept on using UMTS. Curve 2 represents the packet performance when our algorithm was carried out. According to the data report in trace file, only 4 packets were lost while 44 packets were transmitted, so the packet loss rate was 0.09.

Therefore, our algorithm performs well on low packet loss rate based on velocity considered in the whole decision making procedure.

(ii) Execution Time of Proposed Algorithm

If a new case can be found in the CB, the average execution time of the algorithm is less than 1ms;if not, it is between 7ms and 15ms, which includes the time spent in searching for similar cases in CB, decision making and writing a new case into CB. However, as cases in CB get more and more plentiful by self-learning, the possibility of finding a similar case in the CB is getting bigger. When the CB gets stable to some degree, the average execution time almost equals to 1ms, an idea value for multi-criteria handoff. This can obviously embodies the benefit contributed by KR.

5 Conclusions and Future Work

In this paper, an autonomic connection management mechanism is proposed, which includes making handoff decisions for connections, influencing some behaviors of the MT and BSs/APs during handoff and managing the CIL. For multi-criteria handoff decision making, an algorithm combining AHP and SAW was used. Through simulations, we can see that the mechanism reduced packet loss rate by considering an MT's velocity and CBR contributed to the short time of handoff decision.

Our future work includes the prototype validation of the proposed mechanism in heterogeneous wireless access networks.

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