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Handover Management in Enhanced MIH Framework for Heterogeneous Wireless Networks Environment

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Abstract Vertical handover decision making is one of the key problems in heterogeneous networks environment. In IEEE 802.21 standard, a Media Independent Handover (MIH) framework is proposed to improve user experience of mobile devices by facilitating handover in heterogeneous networks with measurements and triggers from link layers. However, vertical handover decision making can benefit from the information more than link layers. In this paper, an Enhanced Media Independent Handover (EMIH) framework is proposed by integrating more information from application layers, user context and network context. Given such information, there is also another important problem on how to select a favorite network. Two quite important problems from realistic scenario are as follows: (1) how to make use of partial knowledge due to incomplete value measurement on decision factors; (2) how to deal with robustness problem due to inaccurate measurement on decision factors. In order to tackle these problems, two novel Weighted Markov Chain (WMC) approaches based on rank aggregation are proposed in this paper, in which a *favorite network* is selected as the top one of rank aggregation result fused from multiple ranking lists based on decision factors. Moreover, an entropy weighting method, combined with WMC approach, is studied. The simulations demonstrate the effectiveness of these proposed approaches.

Keywords Heterogeneous wireless networks · Vertical handover decision · Network selection · Rank aggregation

1 Introduction

Integrated all-IP network has been considered as one of the most potential infrastructures for 4G network, which includes IEEE 802.11 Wireless Local Area Networks (WLAN), IEEE 802.16 Wireless Metropolitan Area Networks (WMAN), Wireless Wide Area Networks

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(WWAN) such as General Packet Radio Service (GPRS) and Universal Mobile Telecommunications System (UMTS) in addition to wired access networks. The converged network obviously has great potential to provide better services to subscribers, and satisfy various requirements such as coverage, high data rate etc. However, great differences between traditional homogeneous and new heterogeneous networks environment make horizontal handovers no longer satisfy the requirements of seamless mobility in heterogeneous networks environment. Vertical handover is therefore necessary to be supported to guarantee service continuity in heterogeneous networks environment. Recently much attention has been paid on vertical handover decision making and many projects have been started with relevant studies such as Ambient Networks [1], Wireless World Initiative New Radio (WINNER) [2], Ubiquitous Japan (u-Japan) evolved from e-Japan [3] and Mobile Ubiquitous Service Environment (MUSE) [4]. Moreover, System Architecture Evolution (SAE) in 3rd Generation Partnership Project (3GPP) is dedicated to interworking and handover signaling. Seamless mobility is then expected to be achieved among different packet-switched domains in different access networks [5].

A new specification namely IEEE 802.21 Media Independent Handover (MIH) [6], is emerging to provide link intelligence and other related network information to upper layers. Meanwhile the independence from particular terminals or radio networks is preserved while generic link layer intelligence is expected to provide as much as possible. More information is therefore integrated into handover decision making. Moreover the requirements of network operators and subscribers are also intended to be satisfied by cooperative use of both mobile terminal and network infrastructure. As a result, more reasonable handover decision is obtained and user experience of mobile devices is enhanced. References [7–9] describe MIH related studies, which mainly focus on seamless mobility service provision, proactive handover performance optimization and deployment of handover frameworks in heterogeneous networks environment. But few have considered the MIH framework combined with corresponding vertical handoff decision algorithm.

In this paper, two major issues involved in mobility management are as follows.

1.1 Information Collection Mechanism in Both Network Side and Client Side

In MIH, the handover initiation process is typically dependent on measurement and trigger mechanism working on the link layer of terminals. However, the effects of the application and user context information are ignored. This paper proposes an Enhanced Media Independent Handover (EMIH) framework for information collection mechanism in which more trigger events and information will be used to facilitate handover decision making. The information can be categorized into four types, including link layer, application QoS, user context and network context.

1.2 Handover Decision by Selecting a Network from Multiple Candidates

Given the above information, the next issue is how to make handover decision by selecting a network from multiple candidates. In this case, several problems should be explicitly studied as follows: (1) not all decision factor values are necessary to be measured for some networks. Therefore, how to make use of such partial knowledge becomes quite important. (2) The measurements are possibly inaccurate for some decision factors, in which case, the network selection should be robust. In this paper, different decision factors are constructed into a hierarchical structure. A new approach is then proposed for network selection in heterogeneous wireless network environment. At first, the candidate networks are ranked by each decision factor and multiple decision factor based ranking lists are obtained accordingly. These ranking lists are then aggregated into a new ranking list according to a certain criterion and the top one network of new ranking list is finally considered as *a favorite network*. The key technical issue here becomes how to aggregate multiple ranking lists into one. Two weighted Markov chain (WMC) based approaches WMC1 and WMC2 are therefore proposed and examined with simulations. By using the proposed approaches, partial knowledge due to incomplete measurement can be easily used. In order to tackle robustness issue, an entropy weighting approach is studied by combining with WMC based approaches.

The remainder of this paper is organized as follows. In Sect. 2.1, an overview of MIH is given. In Sect. 2.2, the framework of EMIH is presented. In Sect. 2.3, a new set of decision factors and related trigger events is proposed. In Sect. 3.1, three traditional network selection approaches are introduced. In Sect. 3.2, two kinds of WMC based approaches are proposed. In Sect. 3.3, experiments are performed to evaluate the effectiveness of our proposed WMC based approaches. In Sect. 3.4, the entropy weighting approach is presented and the simulations are conducted to demonstrate the performance of entropy weighting approach. In Sect. 4, an implementation of whole vertical handover is demonstrated. Finally conclusions and discussions are given in Sect. 5.

2 A Framework of Enhanced Media Independent Handover

2.1 Overview of Media Independent Handover

The IEEE 802.21 standard supports cooperative handover decision making according to information from both client side (mobile nodes) and network side (operators). The mobile node (MN) is well-placed to detect available networks. Meanwhile the position of network infrastructure makes it appropriate to store overall network information, such as neighborhood cell lists, location of mobile devices, and higher layer services availability. The decisions on connectivity can be made in both mobile node and network. MIH Function (MIHF) is one of the key components in the 802.21 standard's framework which provides services to MIH users through a single media independent interface (MIH service access point) and obtains services from the lower layers through a variety of media dependent interfaces (media specific Service Access Points (SAP)). The services provided by MIH Function are as follows:

- Media Independent Event Service (MIES) detects and delivers triggers from both local and remote interfaces corresponding to dynamic changes in link characteristic, link status and link quality. Events may indicate changes in state and transmission behavior of the physical, data link and logical link layers, or predict state changes of these layers. The Event Service may also be used to indicate management actions or command status on the part of the network or some management entity.
- Media Independent Command Service (MICS) enables higher layers to control physical and link layers (lower layers). The higher layers may control the reconfiguration or selection of an appropriate link through a set of handover commands.
- Media Independent Information Service (MIIS) provides a framework and corresponding mechanisms by which an MIHF entity may discover and obtain network information existing within a geographical area to facilitate the handovers. The MIIS typically provides static link layer parameters such as channel information, the Media Access Control address and security information of a Point of Attachment.

Therefore multiple services are deployed in 802.21 to optimize vertical handover. In MIH, link layer intelligence and other related network information is provided to upper layers. The information from application layer and user-aware information are not used on the mobility decision. It motivates us to propose an Enhanced Media Independent Handover Framework, which can provide more effective mobility management.

2.2 Enhanced Media Independent Handover Framework

An enhanced media independent handover framework is proposed to improve the performance of mobility management among heterogeneous networks, which is shown as Fig. 1. The motivation is to make full use of the available information in both client side and network side to optimize handovers. New function entities and modules are introduced to provide link layer, application layer, user context and network context information to mobility decision engine. EMIH deploys comprehensive trigger event criteria and flexibly collects the static and dynamic information available at MN and within the network infrastructure, which will be used to optimize handover decision making in the proposed framework. It should be emphasized that overall mobility management architecture possibly includes Mobile IP infrastructure (client, HA and so on) or any other mobility schemes. EMIH benefits from the application dependent information and user-aware information on mobility. Figure 1 illustrates the key entities both in client side and network side.

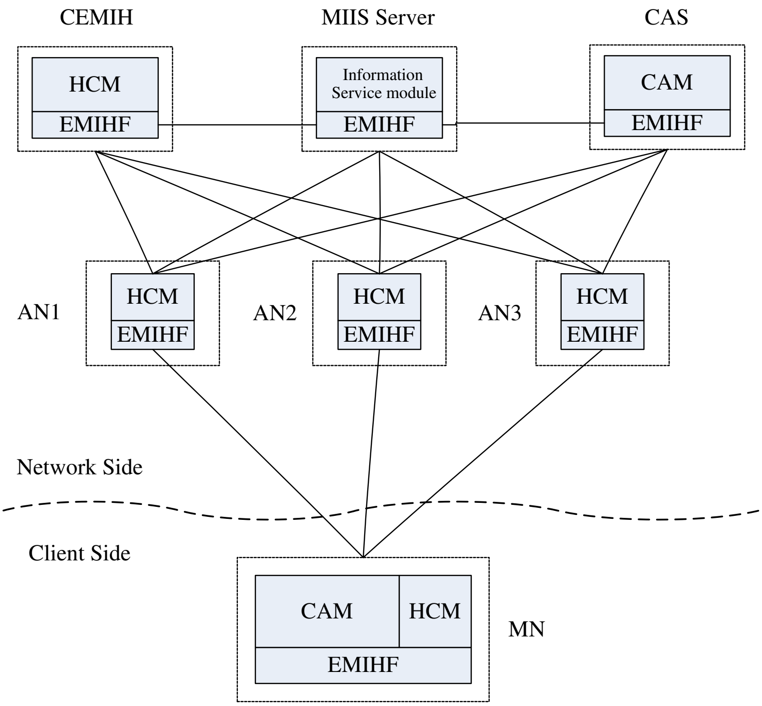

Fig. 1 Enhanced media independent handover architecture

2.2.1 Client Side

EMIH consists of three important entities in MN as follows:

- EMIHF (EMIH Function): EMIHF is a logical entity that facilitates handover decision making. It not only provides multiple link layer intelligence to higher layer, but also offers a unified interface between different access schemes and different upper layer applications. The services include MIIS, MIES and MICS.
- CAM (Context-Aware Module): CAM identifies information of MN and then generates trigger events accordingly. The information consists of application QoS, user context and the capability of MN. The trigger events include Application_QoS_Change and User_Context_Change with details in Sect. 2.3. The trigger events and related information are then transferred to HCM through EMIHF to facilitate handover decision.
- HCM (Handover Control Module): HCM has capabilities to support MN controlled handover in client side. The trigger events are transferred into HCM and facilitate handover.

There are two sub-modules in HCM, namely trigger Function Entity (FE) and handover FE. The trigger FE provides the functions as follows:

- Subscribing trigger events from CAM, CAS (Context-Aware Server) or link layer;
- Collecting and identifying various triggers;
- Filtering events according to trigger criteria;
- Preparing necessary events for handover FE after triggered.

Trigger mechanism is intelligently realized in trigger FE. The handover decision is then made in handover FE. Finally handover is performed and some mechanisms are adopted to maintain service continuity (e.g. context transfer, resource reservation).

Various trigger events are transmitted into trigger FE by EMIHF. Once the trigger FE makes a decision to initiate a handover, it will notify the handover FE. And then handover FE selects a favorite network intelligently.

2.2.2 Network Side

Main entities include Access Network (AN), Media Independent Information Service Server (MIIS Server), Context-Aware Server (CAS), Control EMIH (CEMIH).

- Access Network (AN): The basic entity in network side is EMIHF. HCM in AN has capabilities to support network controlled handover. There are also two components in HCM of AN. The trigger FE receives the trigger events and the handover FE controls intra-domain handover. The signaling is terminated at AN so that the handover procedure is simplified without participation of core network.
- MIIS Server: MIIS Server has two entities: EMIHF and Information Service module. The network related information is collected by MIIS Server and can be accessed by EMIHF in other entities.
- CAS: CAS dynamically identifies network context and then generates trigger events accordingly. The trigger event offers the information of network context change, which is denoted by Network_Context_Change with details in Sect. 2.3. The generated trigger event is transmitted from CAS to subscribers (e.g. HCM in AN) through EMIHF.
- CEMIH (Control EMIH): CEMIH includes EMIHF and HCM. In heterogeneous environment, the network is divided into different administrative domains. Centralized management may be necessary when inter-domain handover happens. CEMIH belongs to

a centralized control entity and provides some controlling functions. There are several functions in CEMIH including collecting trigger events, initiating a handover, controlling handover signaling and selecting a target network. In addition, CEMIH reserves resources for a handover and provides necessary guidances for handover. The centralized management mode ensures a comprehensive information collection mechanism and a reasonable decision making within whole domain. More flexibility can be obtained by combining with different mobility protocols and location management.

In summary, all logical entities communicate with each other through EMIHF, which is implemented in either client side or network side. CAM or CAS identifies the useful information (e.g. application layer information, user context or network context). New trigger events are generated and then transmitted to HCM through EMIHF. HCM makes use of information of Lower (L2/L1) layers and higher layers from client side or network side. A reasonable handover decision will be obtained thereafter.

2.3 Trigger Events and Related Decision Factors

In general handovers may be initiated either by mobile node or by network. The current 802.21 specification explicitly defines events that may be relevant to handover decision, which may originate from MAC, PHY or MIHF either at mobile node or at network point of attachment. Thus, the source of these events may be either local or remote. In addition, the specification defines several categories of events, such as MAC and PHY State Change events, Link Parameter events, Predictive events, Link Synchronous events, Link Transmission events. All of these events are related with link quality information. Thus, link information is a key decision factor for handover decision. However, in heterogeneous network environment, handover may be triggered not only by link quality information, but also by other factors, such as application QoS, user context and network context. As an example, when the type of service is changed from voice to video, it is preferable to use a new network with high data rate. In this case, network selection and handover is decided by QoS requirement. Events may originate from upper layer. In this paper, a new hierarchical structure of decision factors is proposed and the related trigger events become more sufficient than MIH.

Figure 2 shows a hierarchical structure of all decision factors, each of which has a related trigger event. Media Independent Event Service detects events which are originated either locally or remotely. Triggers are then delivered from local and remote interfaces. In Fig. 2, the decision factors are initially categorized into four classes including link quality, application QoS, user context and network context. Each class are classified into several sub-classes further.

Compared with MIH, EMIH defines some new trigger events in addition to link layer triggers. These new trigger events are generated by some sources such as application layer, which are ignored in MIH. The decision factors and the trigger events are discussed as follows:

2.3.1 Link Information

The event service for link information is the same as the definition in the current IEEE 802.21 specification [6]. Several categories of events include MAC and PHY State Change events, Link Parameter events, Predictive events, Link Synchronous events, Link Transmission events.

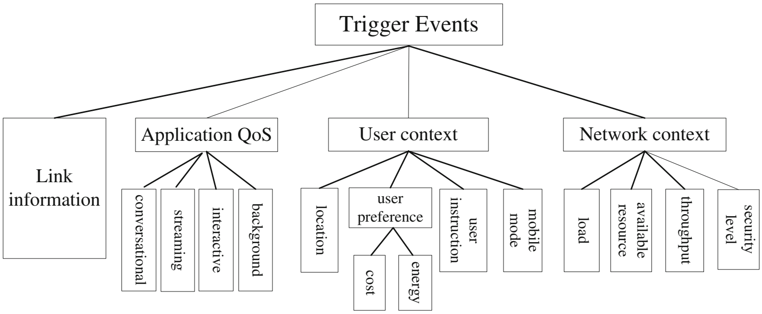

Fig. 2 Hierarchical structure of trigger events

2.3.2 Application QoS

The trigger event for application QoS is Application_QoS_Change originally defined in EMIH. This event includes:

- Trigger Event Type: {Application_QoS_Change};
- Source: {Upper layers};
- Parameters: {Network identifier, Traffic class, QoS parameter}.

Application_QoS_Change indicates changes of user traffic and the corresponding QoS requirements. Here network identifier refers to the current network ID of trigger source. Traffic class indicates QoS class of services, including conversational class, streaming class, interactive class and background class [10]. Different delay sensitivities exist in different classes. Conversational and streaming classes are generally regarded as real time services whose performance is highly sensitive to delay and delay jitter. Interactive and background classes are non-real time services with packet loss as a key factor. If user requirements are not satisfied or better experience is available in another access network, network selection and handover will be triggered. Then QoS paprameters will be transmitted to handover FE and used as some decision factors to select a favorite network.

2.3.3 User Context

User_Context_Change originally proposed in EMIH indicates changes of user context information. This event includes:

- Trigger Event Type: {User_Context _Change}
- Source: {Upper layer}
- Parameters: {Network identifier, User grade, User_aware context}

User grade is an indicator parameter which is determined by the negotiation in network side. The related information can be stored either in network side or in client side. User context is composed of location information, mobile mode, user preference and user instruction, in which a reasonable handover is favorable. In terms of location information there are various environments such as urban, suburban or rural regions. Mobile mode consists of indoor mode, high speed mobile or nomadic mode, in which handover is triggered by the change of mobile speed and directions. User preference indicates cost and/or energy preferable by users and user instruction means the favorite network for a specific user.

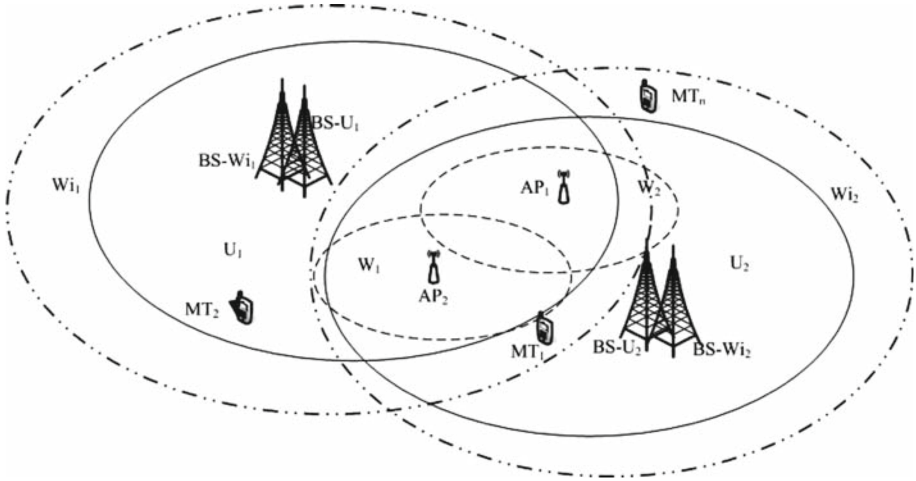

Fig. 3 Simulation scenario

2.3.4 Network Context

Network_Context_Change, originally proposed in EMIH, indicates changes of network context. This event includes:

- Trigger Event Type: {Network_Context_Change}
- Source: {Upper layer}
- Parameters: {Network identifier, Network context}

Network context information includes load, available resource, throughput and security level. In particular, security level is one of the key decision factors and can not be replaced by others. It should be emphasized that low security level will not be accepted by majority of users even the network performs well.

With the above-mentioned fruitful information, EMIH could facilitate handover decision more effectively and precisely in heterogeneous networks environment. Consider a scenario illustrated in Fig. 3, a user begins with a VoIP connection in the area which is covered by a WLAN network. Then this user leaves out of the coverage of the WLAN network and moves into another area covered by both a UMTS network and a WiMAX network. Once the user is out of the coverage of the WLAN, QoS of the VoIP service is deteriorated and a trigger message is sent from link layer to EMIHF. Moreover EMIHF receives packet loss rate information from application layer and user context from CAM. At the same time, static information about candidate networks has been collected by MIIS Server. EMIHF then sends event triggers and the related information to HCM for handover decision. Because the user can be in either UMTS network or WiMAX network, the network selection should be done in HCM. For the VoIP services, a low bandwidth is enough but the delay requirement is quite stringent. Both UMTS and WiMAX network can actually satisfy the low bandwidth and stringent delay requirement of the VoIP service. However, the user context information collected by CAM indicates that the user prefers a low cost network. As a result, WiMAX is selected by HCM because it has lower cost than UMTS network.

3 Network Selection Based on Rank Aggregation

3.1 Overview of Previous Approaches on Network Selection

In recent years, more efforts are focused on the topic of network selection. The previous approaches on network selection can be roughly categorized into three classes, namely, policy based, fuzzy logic based, and multiple attribute decision making (MADM) based approach.

In the policy based approach [11], a cost function is defined and users are allowed to design rules on the judge of the best wireless network. The effects of different networks are considered carefully and a good tradeoff is tried to be found.

In the logic based approach [12–14], the fuzzy logic inference system is used as follows. The decision factor dependent member functions are applied on the values of decision factors. The degree of truth for each rule premise is then obtained. The truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. All of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Finally the fuzzy output set is transferred to a real number for each network and the best network is then selected.

In MADM based approach, network selection is formulated as a fuzzy multiple attribute decision making problem and some classic methods for MADM can be applied. In [15], simple additive weighting (SAW) and technique for order preference by similarity to ideal solution (TOPSIS) are used. In [16], analytic hierarchy process (AHP) and the grey relational analysis (GRA) are adopted. Moreover performance comparisons among these methods are done in [17] and a new method namely multiplicative exponent weighting (MEW) is presented.

Those network selection algorithms discussed above have a common assumption that the accurate values of all decision factors are derived before network selection. However it is not true in many realistic scenarios. It is possible that some decision factors can not be measured or the measurements are not accurate enough for the utility of the network selection. Given such problem, there are two issues to be considered: (1) with only incomplete network information, how to make network selection; (2) how to make the selected result more robust.

3.2 Weighted Markov Chain Based Approach

Network selection with multiple decision factors can be formulated as a rank aggregation problem, in which a "better" ranking can be derived by combining ranking results of the different decision factors. Recently, more and more efforts are focused on the topic of rank aggregation because this topic is one of the key issues in web search area.

In [18], three methods namely linear combination method, Borda count and Markov chain (MC) method are reviewed and compared with web search application. Among three methods, MC method is preferable in handling partial ranking lists and integrating application dependent heuristics, which make it very attractive to network selection with multiple decision factors. MC method begins by constructing a Markov chain transition matrix on given partial/full ranking lists. A priori knowledge and/or user experience can be naturally involved with particular definition of element in Markov chain transition matrix and particular weight for ranking lists of decision factors. Stationary probability distribution is then derived and used to sort candidate networks. The favorite network is finally selected as the candidate network with the largest value of stationary probability. In this section, two kinds of weighting Markov chains methods WMC1 and WMC2 are proposed with difference on construction of Markov chain transition matrix as follows.

Consider a candidate network set $P = \{p_1, \ldots, p_N\}$ and a decision factor set $Q = \{q_1, \ldots, q_M\}$ where N is the number of candidate networks and M is the number of decision factors. For decision factor q, a ranking list is obtained as an ordering of a subset $P_{sub} \subset P$, i.e. $\tau_q = \left\{p_1^q \geq p_2^q \geq \cdots \geq p_N^q\right\}$ where "$\geq$" represents some ordering relation on P_{sub}. Also, if $p \in P_{sub}$, let $\tau_q(p)$ denote the position or rank of p in τ_q. Moreover, let $\Psi(p) \in Q$ represents the decision factor subset whose ranking lists include network p.

With above definitions, WMC1 method is described as follows:

1. Normalization of decision factor weight:
   (a) Every decision factor is given a normalized weight in which the weight of decision factor q is denoted by w_q with constraint as $\sum_{q \in Q} w_q = 1$.
2. Construction of weighted Markov chain transition matrix MC:
   (b) Initialize a $N \times N$ matrix $MC = \left\{mc_{ij}\right\}$ with all element values are equal to 0, in which mc_{ij} represents transition probability from p_i to p_j.
   (c) For each $\tau_q(p), q \in Q$, MC is updated as follows:
      (i) For each mc_{ij} in MC, update

$$mc_{ij} = mc_{ij} + \frac{1}{\tau_q(p_i)} \frac{w_q}{\sum_{q \in \Psi(p_i)} w_q} \tag{1}$$

If $p_i, p_j \in P$ and $\tau_q(p_i) \geq \tau_q\left(p_j\right)$
It is possible for some partial ranking lists not including network q and have no effects on network q. So other ranking lists make up a new subset of Q and the ranking lists in this subset is then re-normalized as $w_q / \sum_{q \in \Psi(p_i)} w_q$ instead of w_q.
      (ii) Repeat the above step until all $\tau_q(p), q \in Q$ are examined.
3. Computation of stationary distribution (row) vector SD:

$$SD = SD \times MC \tag{2}$$

where $SD = \{sd_1, \ldots, sd_N\}$ and sd_n is the element for network p_n
4. Selection of favorite network p_γ:

$$\gamma = \arg\max_n sd_n \tag{3}$$

WMC2 method is similar to WMC1 with only difference in step 2(b) as follows:

(b) If not all For each $\tau_q(p), q \in Q$, MC is updated as follows:
   (i) For each mc_{ij} in MC, update

$$mc_{ij} = mc_{ij} + \frac{1}{N_q} \frac{w_q}{\sum_{q \in \Psi(p_i)} w_q} \tag{4}$$

If $p_i, p_j \in P$ and $\tau_q(p_i) > \tau_q\left(p_j\right)$

$$mc_{ij} = mc_{ij} + \frac{N_q - \tau_q(p_i) + 1}{N_q} \frac{w_q}{\sum_{q \in \Psi(p_i)} w_q} \tag{5}$$

If $p_i, p_j \in P$ and $\tau_q(p_i) = \tau_q\left(p_j\right)$
   (ii) Repeat the above step until all $\tau_q(p), q \in Q$ are examined.

According to [19], two preference weighting methods are used. In the first method, weights are assigned according to different service types. VoIP, streaming, and web browsing are used to decide weight values. In the second method, user subscription types such as gold, silver, and bronze are used to assign weights. In this paper, a uniform weighting method, in which all weights are equal to $1/M$, is adopted to simplify the comparative experiments between proposed approaches and traditional approach. Another entropy weighting method is then studied which is suitable for the robustness problem in Sect. 3.4.

3.3 Evaluation of Network Selection

In order to compare performances of different approaches, a multi-user scenario is designed and illustrated in Fig. 3. The candidate network set consists of two UMTS networks (U_1, U_2), two WiMAX networks (Wi_1, Wi_2) and two WLAN networks (W_1, W_2). For each pair of (U_n, Wi_n) $n = 1, 2$, the corresponding base stations $BS - U_n$, $BS - Wi_n$ have the same positions for $n = 1, 2$. Moreover the coverage radiuses in a certain cell by UMTS, WiMAX and WLAN are set to 1000 m, 1200 m and 100 m, respectively.

In the simulation, there are four types of service consisting of VoIP and three kinds of data services with different bandwidth requirements. The bandwidth requirement of VoIP service is 12.2 kbps and the minimum bandwidth requirement for three kinds of data services are 0.5 Mbps, 1 Mbps and 2 Mbps, respectively. The arrival rates of both VoIP service and three data services follow the Poisson distribution and the arrival rate ratio between VoIP and data services is equal to 2:1. Mean holding time follows exponential distribution with parameters as mean denoted by $1/\mu_v$for VoIP service and mean denoted by $1/\mu_d$ for data services. In the simulation, $1/\mu_v$ is set by 120 s and $1/\mu_d$ is set by 300 s. The mobile users are fixed during the simulation period.

Moreover, according to [19], several decision factors are used as follows, which could be collected dynamically by EMIH. And the decision factor values are initialized as Table 1, which is then updated in the following period.

- Total bandwidth (TBW): TBW indicates how much bandwidth is available for a candidate network.
- Allowed bandwidth (ABW): ABW indicates the bandwidth allowed by the candidate network for single user.
- Delay (D): D represents the average packet delay within the network.
- Packet loss (L): L measures the average packet loss rate within the network.
- Cost per byte (C): C means relative transport cost of operator for a particular access network.
- Load (Ld): Ld represents the ratio of allocated bandwidth to the total bandwidth.

Table 1 Initialized decision factors values

	D (ms)	L (per10^6)	ABW (mbps)	TBW (Mbps)	C (price)	Ld (%)
UMTS1	35	70	0.5	2	0.6	0
UMTS2	30	80	0.6	2	0.8	0
WLAN1	100	20	1	11	0.1	0
WLAN2	140	18	1.5	54	0.05	0
WiMAX1	60	15	2.5	100	0.5	0
WiMAX2	70	20	3	100	0.4	0

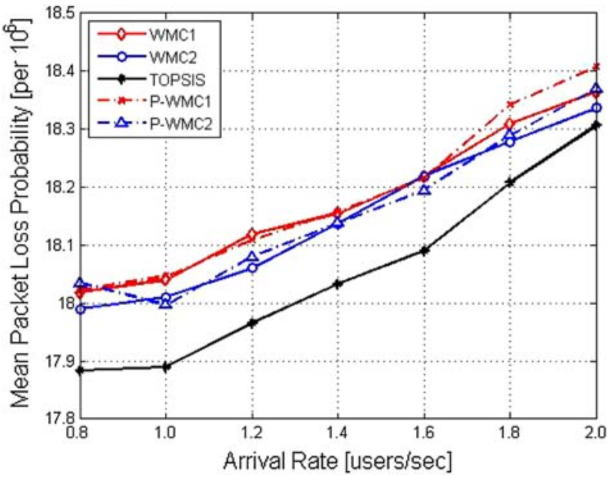

Fig. 4 Mean packet loss probability

In the simulation, WMC1, WMC2 and TOPSIS are studied. Moreover, WMC1 and WMC2 with partial rankings namely P-WMC1 and P-WMC2 are also investigated in which decision factor D of W1 and W2 are assumed not to be measured. The simulation results are illustrated in Figs. 4, 5, 6, 7, respectively.

In Fig. 4, the performance on packet loss of proposed WMC1, WMC2 is slightly higher than TOPSIS. Moreover it is observed that P-WMC1 and P-WMC2 is comparable to WMC1 and WMC2. In Fig. 5, the performance on mean delay of VoIP users with WMC1 is consistently better than TOPSIS when the arrival rate varies from 0.8 to 2.0. In the meanwhile, the performance difference between P-WMC1 and WMC1 is much small and same observations can be obtained between P-WMC2 and WMC2. In Fig. 6 on mean delay of data users, WMC1, which is only worse than WMC2, also performs consistently better than TOPSIS. However both P-WMC1 and P-WMC2 performs worse than WMC1 and WMC2 respectively. In Fig. 7, WMC1 and WMC2 are both better than TOPSIS, while P-WMC1 and P-WMC2 have the similar performance in terms of total allocated bandwidth.

3.4 Entropy Weighting Method for Robustness Issue

In order to analyze the influence of the inaccurate measurement of the decision factors on the performance of the network selection, the simulation scenario is defined as follows. VoIP is adopted as the user service. Three decision factors are used including average delay (D), average packet loss (L), cost per byte (C). The corresponding network selection result is derived by using uniform weighting method. Given these decision factors, the network selection is done by using WMC1 algorithm to select an optimal network among the three candidate networks as UMTS, WiMAX and WLAN.

In Table 2, the accurate values of each decision factor are given for different networks and used in the network selection. Table 3 provides a comparison of results for WMC1 when the decision factor values for packet loss are changed by 10%. It can be observed that WiMAX is selected to be the best network among three candidate networks when there is no measurement error. This result is reasonable because WiMAX can provide a minimum packet loss rate, a minimum cost and a middle average delay.

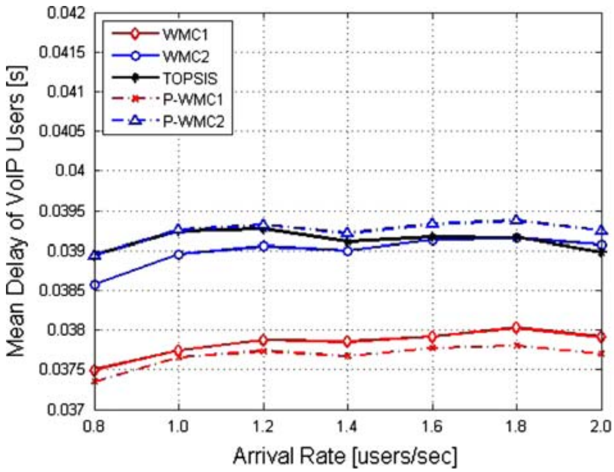

Fig. 5 Mean delay of VoIP users

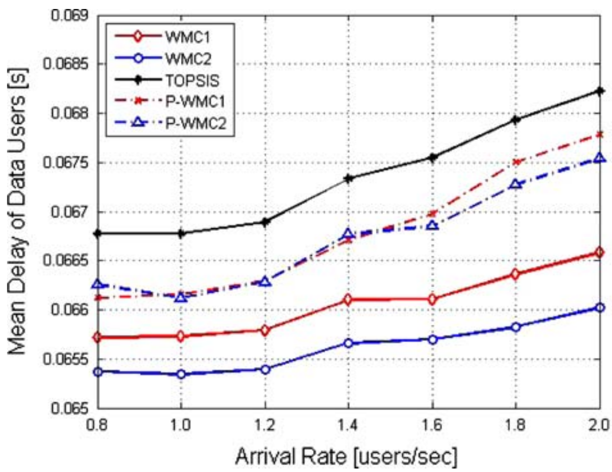

Fig. 6 Mean delay of data users

However if the inaccurate measurement happens, the case becomes quite different. By using uniform weighting method, WLAN is selected. The reason is that WLAN can provide minimum packet loss rate and lowest cost which however is due to inaccurate measurement.

Obviously, the more robust the decision factor is to noise, the larger the corresponding weight should be given. In order to tackle the robustness problem, the EW method [20] is proposed to set the weight of each decision factor. In EW method, the decision factor weight is the function of differences among values of the decision factor and more value differences mean that the corresponding decision factor is given a larger weight. When there is no any priori knowledge, it is a reasonable assumption that the noise and user preference is the same for all decision factors. As a result, it makes sense by using EW method to initiate the decision factor weight.

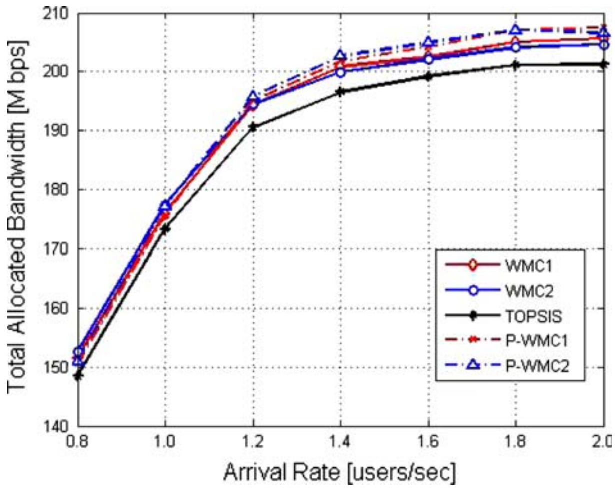

Fig. 7 Total allocated bandwidth

Table 2 Decision factor values

	D (ms)	L (per10^6)	C (price/byte)
UMTS	35	70	0.6
WiMAX	60	19	0.5
WLAN	100	20	0.1

In addition to the definitions in Sect. 3.2, let us define $x\left(p_i, q_j\right)$ as the value of network p_i in decision factor q_j and $x^{noise}\left(p_i, q_j\right) = x\left(p_i, q_j\right) + n$ where n is the noise. The procedure for EW method is then as follows:

1. A $N \times M$ normalized matrix is derived with element as follows:

$$\mathrm{Pr}_{ij} = \frac{x^{noise}\left(p_i, q_j\right)}{\sum_{i=1}^{N} x^{noise}\left(p_i, q_j\right)} \tag{6}$$

2. Shannon entropy is then obtained for the jth decision factor as follows:

$$E_j = -\frac{1}{\ln N} \sum_{i=1}^{N} \mathrm{Pr}_{ij} \log \mathrm{Pr}_{ij} \tag{7}$$

3. Entropy weight w_j is calculated for the jth decision factor as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{8}$$

where $d_j = 1 - E_j$.

In order to validate the effectiveness of proposed method, a simulation is conducted to compare EW method with uniform weighting (UW) method. Four candidate networks denoted by $\{p_1, p_2, p_3, p_4\}$ and two decision factors denoted by $\{q_1, q_2\}$ are used and ranking list of

Table 3 Simulation results for network selection

Networks	UMTS	WiMAX	WLAN
SD without error	0.2432	0.4324	0.3243
SD with 10% error	0.2222	0.2222	0.5556

Table 4 True value of decision factors

	p_1	p_2	p_3	p_4
q_1	11	12	13	14
q_2	10	20	30	40

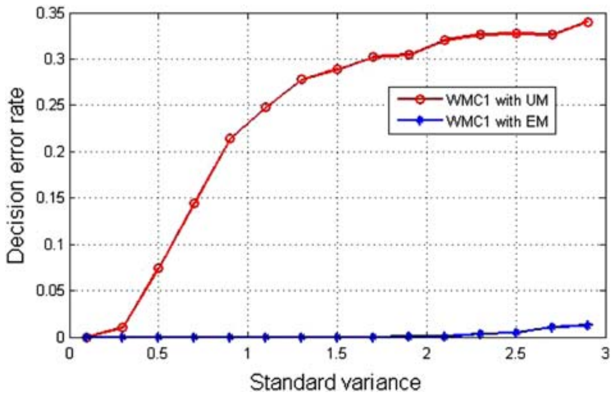

Fig. 8 Decision error rate

networks is $\{p_1 \geq p_2 \geq p_3 \geq p_4\}$. Both factors can give correct rankings whose true values are shown in Table 4.

Additive white Gaussian noise (AWGN) is then assumed as the noise with probability density function as follows:

$$p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{n^2}{\sigma^2}\right) \tag{9}$$

where σ is standard deviation.

Given the noisy model, a noisy value $x^{noise}(p, q)$ is generated for the candidate network p and decision factor q. WMC1 is then adopted for network selection. This simulation is repeated 5,000 times and the evaluation measure namely *decision error rate* is defined as the ratio between the number of decision error and the total number of simulations.

The simulation result is demonstrated in Fig. 8. When σ is larger than 0.3, it is observed that *decision error rate* is quickly increased by using UW method. However *decision error rate* is still equal to 0 in EW method until σ is larger than 2. We can make a conclusion that EW method performs much better than UW method when different decision factors share the same noise model.

4 Implementation of Mobility Management

In this section, the detailed procedure of mobility management is described. The process on effective mobility management in EMIH architecture mainly includes three steps, shown in Fig. 9.

4.1 STEP 1: Obtaining Trigger Events and Information Related with Handover

The handover process may be conditioned by the measurements and triggers offered by different sources such as link layer or application layer in MN, or network context from network side.

When the event originates at any layers of the protocol stack within an MN or network entity, EMIHF on that entity obtains the event locally through the service primitives of the SAPs which define the interface of EMIHF with the layer. When the event originates at a remote network, the EMIHF on the local network obtains event through MIH message and exchanges with a peer EMIHF that resides in the remote network. And then events are dispatched to EMIH users that have subscribed or queried these events in the local stack.

4.2 STEP 2: Handover Decision Making, Network Selection and Resource Negotiation

If a handover is triggered, a favorite network is selected by WMC based rank aggregation approach. Current network then sends handover preparation request to target network, with the information of MN capability and context. The MN context includes a permanent user identity and other information, e.g. security and IP bearer parameters. The target network will reserve resources according to requirements of MN to reduce interruption time.

4.3 STEP 3: Handover Execution and Resource Release

Mobile IP (MIP) [21] or Session Initiation Protocol (SIP) [22] may be adopted for mobility management in 4 G mobile system. After network selection and link layer handover, MIP signaling will be exchanged over radio interface to update route. Bi-casting or data forwarding mechanism may be deployed to minimize packet loss. Finally, the resources in source network will be released.

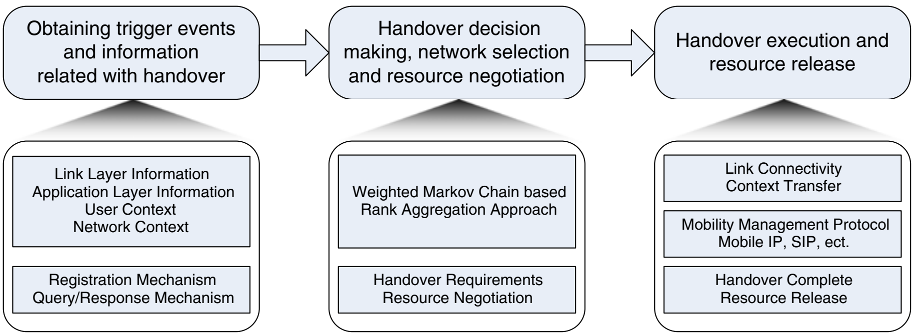

Fig. 9 Procedure of mobility management in EMIH framework

EMIH supports various handover types. For example, handover can be controlled by MN or Network. The type of handover can be selected when the signaling needs to be centralized by CEMIH. In addition, handover can be initiated either by MN or by network. In general, for intra-domain handover, signaling usually terminates at access network in order to achieve faster processing and lower handover delay. While for inter domain handover, CEMIH located in core network may be necessary to provide a unified control.

Figure 10 gives an example of Mobile assistant network control (MANC) handover. Figure 10a is a example that there is no unified control by CEMIH and handover is initiated by MN. Figure 10b is another example with CEMIH control. The procedure possibly needs some modifications in some other handover types.

The Mobile-initiated Handover Procedure, shown in Fig. 10a, is as follows:

(1) MN is associated to AN1. CAM of MN identifies application layer and user context continually;
(2) CAS in network side identifies network context of AN1;
(3) CAS identifies network context of AN2 simultaneously;
(4) According to collected information, CAM or CAS makes decision on generating trigger event;
(5) Application_QoS_Change event is triggered due to higher bandwidth requirement of a new application. The related user context is carried by this trigger and transmitted to HCM of AN1 through EMIH Function;
(6) After received trigger event, HCM queries dynamic network information from CAS accordingly;
(7) CAS responds to HCM with related information;
(8) After received trigger event, HCM queries static network information from MIIS server accordingly;
(9) MIIS server responds to HCM with related information;
(10) Then handover happens.

In this procedure, the trigger can be anyone of the events defined in Sect. 2.3. Thus, effective mobility management decision is achieved in EMIH.

In Fig. 10b, the handover decision is made by CEMIH.

After handover, maybe there are some changes of network status (e.g. load, available bandwidth). Therefore, in order to guarantee users experience, related QoS information in application layer should be adjusted correspondingly. A new command service named Application_QoS_Adjust is defined in this paper. It is used to adjust the QoS information of application before or after handover. This command service will be transferred through EMIHF from network side to client side. Given such command service, the application layer in MN will prepare for the incoming adjustment. If handover has not finished yet, the receiver will degrade the QoS level and adjust coder/decoder rate accordingly. Here, QoS level means QoS class and ARP (Allocation and Retention Parameters) class. There are three priority classifications in all of QoS classes, known as Allocation/Retention priority classification. That is, new priority levels are introduced by ARP. If handover procedure is over, the receiver may resume the original QoS level. Moreover, if Session Initiation Protocol (SIP) is adopted, the session setup requests some characteristics (e.g. bandwidth) of end terminals by using Session Description Protocol (SDP) [23].

In general, handover optimization by using MIH will bring some additional signaling cost, but the performance of handover latency can be improved [24,25]. MIH could trigger a handover in time and obtain the necessary information in advance. Once a handover is triggered, a link will be setup to the target network. The handover interruption

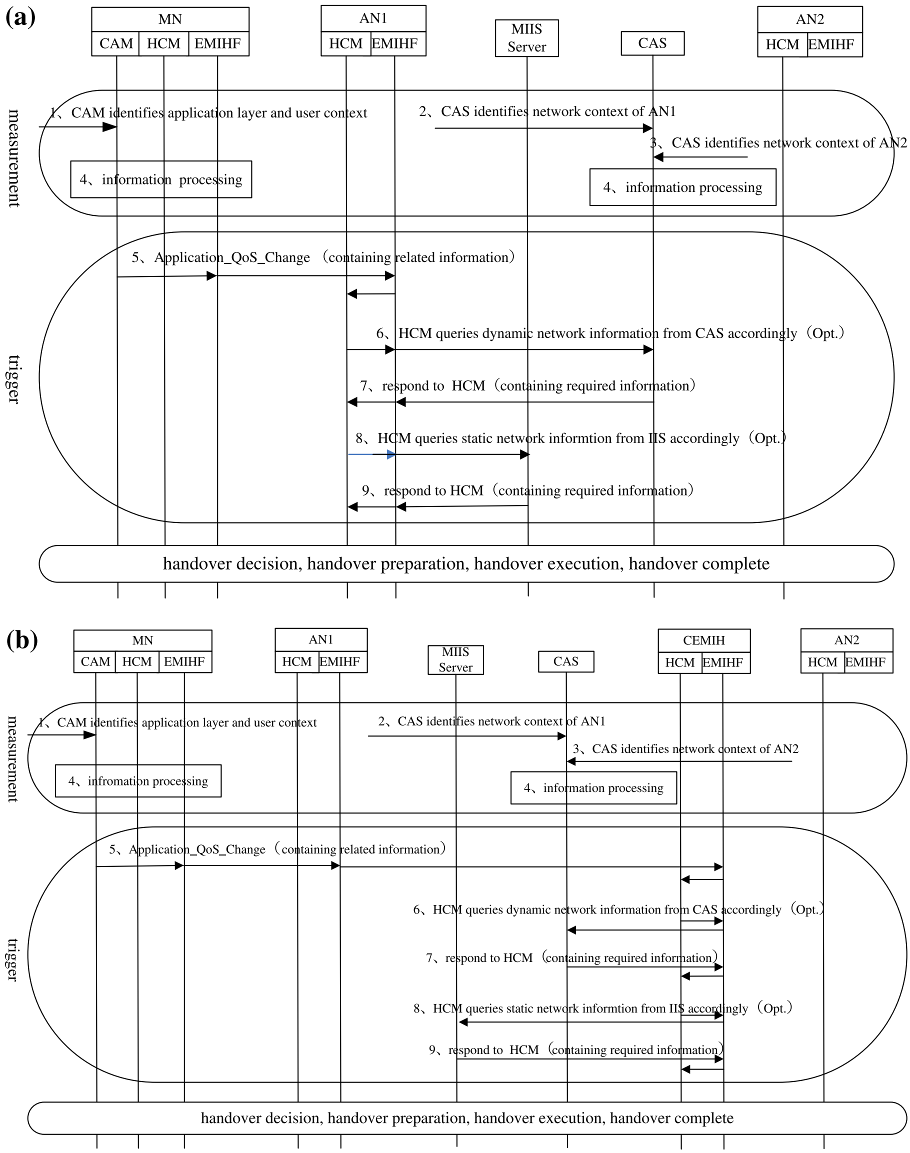

Fig. 10 Examples of MANC handovers

time can be decreased so that lower handover latency and decreased packet loss can be obtained.

The amount of the signaling cost is highly related with the amount of information and the method to get the information. The effective information selection can avoid too much amount of the signaling cost. For example, [25] discussed how to use MIH to optimize Fast Mobile IPv6 (FMIPv6) in vehicular environment, in which a new defined Heterogeneous Network Information (HNI) container selects the necessary information in vehicular networks and help in reducing the message overheads, processing, and lookup/indexing times.

The simulation results show that the 802.21-assisted FMIPv6 has about 50% less signaling overhead than the original FMIPv6 does.

On the other hand, reasonable information collection mechanisms could also decrease the signaling cost. There are two mechanisms to obtain the required trigger events and the related information for EMIH users (HCM or upper layers).

The first mechanism is registration mechanism. The registration mechanism enables an endpoint to register its profile in particular event type. After registration, the EMIH users select a set of events so that they can receive the corresponding notifications from the EMIH Function. The selection on the events is dependent on the realistic network environments.

The second mechanism is query/response mechanism. The query/response mechanism is to retrieve the information. EMIH users send a request to CAM, CAS or MIIS Server. In this case, the registration mechanism is unnecessary. The corresponding response includes either application/user information in client side or the static/dynamic information in network side.

In EMIH, it is worthwhile to study how to effectively make information selection.

5 Conclusion

This paper discusses an enhanced media independent handover framework and its mobility management mechanism based on IEEE 802.21. In this architecture, some new FEs (e.g. CAS, CEMIH) and modules (e.g. CAM) are presented. In addition, comprehensive trigger criteria are defined and various flexible handover schemes are designed to provide seamless and effective mobility management. This mechanism provides adaptive adjustment according to application change, user and network context information. All of events defined in this paper follow the basic criterion of IEEE 802.21 standard. Therefore, the proposed EMIH framework and its mobility management mechanism are easy to implement in IEEE 802.21 standard.

Moreover, a new rank aggregation approach has been proposed for network selection with multiple decision factors. The robustness issue is then studied and a new entropy weighting method combined with rank aggregation approach is presented. The simulation results demonstrate the effectiveness and good potential of proposed approaches. Ongoing and future works includes (1) studying application based weighting method and weighting fusion method with multiple weights; (2) studying more efficient and more application dependent Markov chain generation method; (3) studying better performance evaluation method; (4) developing new rank aggregation approaches by considering robustness issue; (5) investigating the effectiveness of incremental rank aggregation approach by considering the feedback of user and network. More results will be reported elsewhere when they are available.

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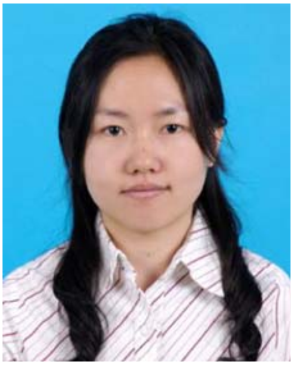

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