A step-wise Vertical Handoff technology for Cellular Multi-hop Networks

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ABSTRACT
With the rapid development of wireless network, the integration of cellular and multi-hop networks is the trend for next generation mobile networks (NGMN). And vertical handoff is really an open and challenge issue in this area. Consequently, in this paper, a multi-step vertical handoff mechanism (MVHOM) is proposed for a cellular multi-hop network (CMN). The mechanism comprises three steps, getting location information based on arrival time in conjunction with radio signal strength (RSS), then dealing with access network selection by weight of QoS factors calculated by an integrated analytic hierarchy process (AHP) and grey relational analysis (GRA) algorithm, and finally triggering a forced vertical handoff to sustain service continuity. Simulations reveal that the proposed MVHOM can effectively improve the quality of service and performance in CMN.

Categories and Subject Descriptors
C.2.1 [Network Architecture and Design]: Wireless communication
C.4 [Performance of Systems]: Design studies

General Terms
Design, Performance, Management.

Keywords
Vertical Handoff, Cellular Multi-hop Networks, Analytic Hierarchy Process, Grey Relational Analysis

1. INTRODUCTION
CMN has garnered a significant amount of attention by now. In a multi-hop network no direct link exists for communication between data source and data sink. Therefore, data is forwarded by relay stations in order to reach its destination. A relay station may also be referred to as forwarding or routing station and may be a mobile or fixed terminal. CMN is a promising candidate technology for next generation wireless networks, where a cell is served by a BS supported by multiple fixed relay stations (FRSs). In these networks, even some mobile stations may serve as relay to forward data in order to increase the coverage area or improve performance of the multi-hop enabled cell.

Typically formed on-the-fly and without requiring preexisting infrastructure or centralized administration, ad hoc networks are often peer-to-peer, with flexible topologies and support for multi-hop routing. The topology of ad hoc networks is typically arbitrary, and multi-hop routing is often necessary, versus one hop from transmitting user to base station and one hop from base station to recipient user in cellular networks. Realistically, ad hoc networks will not likely replace cellular networks. However, cellular ad hoc networks, i.e. cellular networks with relays, may be a possibility for future generation cellular systems [1, 2].

There are many proposals for CMN in literatures. However, they are not specifically designed for supporting mobility management (MM), although MM issues are mentioned in some of these CMN researches. Mobility management (MM) is the substantial functionality to support CMN, while researches on it are scarce. MM contains two components: location management (LM) and handoff management (HOM). Location management enables the system to track the locations of mobile users between consecutive communications. While handoff management is the process by which a user keeps its connection active when it moves from one base station (BS) to another. There are many efficient location management techniques in literatures for next generation wireless networks. These can be used in cellular ad hoc networks. However, seamless support of HOM in CMN is still an open issue [3]. Therefore, we address study HOM in this paper.

Performing handoff from any source to a target system applying the same technologies and relying on the same specifications is referred to as horizontal handoff (HHO). If handoff is triggered to another system using a different technology, the notation vertical handoff (VHO) applies.

Compared to HHO, VHO introduces new degrees of freedom. For example, it is possible that a decision unit triggers VHO execution due to QoS aspects, though the actual link quality in the current cell is excellent. If another vertical system with a multiple of
offered data rate is available, the decision space is no longer restricted to sole link parameters.

In [4] a handoff scheme for integration of cellular and ad hoc networks is proposed. VHO triggering in iCAR is primarily caused by the received RSS which is inadequate decision factors. Therefore MVHOM is proposed in this paper. The mechanism mainly has three steps:

Step 1 Getting the location information based on arrival time and RSS.

Step 2 Dealing with access network selection by weight of QoS factors, which is calculated by an integrated AHP and GRA algorithm.

Step 3 Triggering a forced vertical handoff to sustain service continuity, which depends on the priori time and mobile terminal (MT).

The rest of this paper is organized as follows. First we review the physical characteristics and architecture in CMN. Next, MVHOM based on QoS in CMN is proposed. Afterward, performance results of VHO simulation scenarios are shown and analyzed. Finally, it presents conclusions and future work.

2. CELLULAR MULTI-HOP RELAY NETWORK ARCHITECTURE

Figure 1 shows the physical characteristics of two cells in an emerging CMN system, including the interfaces (type and number) for every individual node. Two air interfaces are utilized for the communication between nodes: the C (cellular) interface that operates at a cellular network frequency (in-band), and the A (ad hoc) interface that operates at an ad hoc network frequency (out-of-band, e.g., IEEE 802.11). The introduction of the two air interfaces on MTs significantly increases the flexibility of network. The BS is same as the present cellular network base stations with C-interface. A BS uses its C-interface to communicate with MTs in a wireless mode. However, the communication between BSs can be in wired mode or using microwave, and controlled by a Central Control (CC) System. Fix relay station (FRS) with managed mobility is introduced to divert the traffic in hotspot areas. It uses both ad hoc technologies and cellular network technologies and as such with one A-interface and one C-interface. In a FRS, a C-interface is used for communicating with a BS or a MT with a C-interface whereas A-interface is equipped for communicating between FRS’s or with MT’s with an A-interface. The MT in the above CMN is designed with more flexibility and can have only one C-interface or only one A-interface or both interfaces to accommodate the diversity of mobile devices in use.

3. MULTISTEP VERTICAL HANDOFF MECHANISM

MT’s mobility across diminished cell sizes to increase capacity in CMN will result in multiple handoffs during the lifetime of an ongoing call. Supporting these handoffs in a transparent manner will be instrumental in providing “always connectivity” — a key feature of CMN. Similar to legacy networks, handoff triggering in CMN will be primarily caused by the received RSS falling below an acceptable level near the cell boundary. VHO relies on the availability of multiple networks at the MT’s present location. Handoff is therefore initiated if a network optimized selection becomes available to enhance the current service quality, as would be the case in a co-located heterogeneous environment. However, there may be considerable delay in handoff initiation and connection setup due to the inability in detecting a handoff and/or lack of resources in the target network, for both forms of VHOs. As a result, it may degrade the application QoS leading to dropped sessions. To guarantee service continuity, a predictive mechanism is therefore required to minimize the overall handoff period, which is at least comparable to the legacy networks. In this paper we propose a periodical VHO algorithm that addresses both forms of handoff by selecting the optimal access network and accurately predicting a forced handoff based on the MT coordinates [10, 11]. The information of the MT’s precise location is imperative to the accuracy of the prediction process from a geographical perspective. The novelty of the algorithm lies in its unified approach in dealing with the above mentioned handoffs.

3.1 Location Management

RSS-based location information can suffer from multi-path propagation and shadowing effects. To reduce the effect of these channel impairments that arise due to the surrounding barrier (e.g., trees, skyscrapers, etc.), the proposed algorithm adopts a mechanism which is based on time of arrival (TOA) in conjunction with RSS. In the positioning mechanism, a distance estimate from the serving BS/FRS is calculated based on the time it takes for the radio signal to travel to the MT. The identity of the serving and surrounding BSs/FRSs are derived from the beacons of cell broadcast only those that meet the RSS requirement, which includes location information such as coordinates of the surrounding cells and their associated parameters. Using the BS/FRS-MT distance estimates from three or more BSs/FRSs, circles are drawn and the coordinates of the MT are derived from the intersection point. Since the BSs/FRSs are synchronized through GPS receivers, accurate timing can be provided, thus eliminating the possibility that the circles may not intersect. This is in principle similar to the geo-location of the indoor GPS system, although other schemes such as pattern recognition can also be used. While it offers a better distance estimate than RSS, TOA-based positioning is not completely immune from multi-
path propagation. In multi-path propagation, the direct-path received signal at the receiver maybe accompanied by delaying because of reflection or diffraction, therefore seriously harming the accuracy of the distance estimates, especially when the multi-paths are very closely spaced in time. On the other aspects, barriers block the direct path between the BS and the MT, and cause the received radio signal to traverse excess path lengths on the order of hundreds of meters, resulting in erroneous estimates. To mitigate these effects, the proposed algorithm adopts [10] as the solutions.

3.2 Network Selection

An access network selection scheme is presented that utilizes location information gathered from section 3.1 and the surrounding cell broadcast. MT discovers the availability of surrounding networks from the broadcast messages arising from individual BSs/FRSs. Based upon the network-specific QoS parameters derived from these broadcasts and the user profile, access network selection is carried out for possible VHO enhancing service quality. The selection process combines two mathematical techniques —AHP [12] and GRA [13] to make decisions.

3.2.1 Analytic Hierarchy Process

AHP is defined as a procedure to divide a complex problem into a number of deciding factors and integrate the relative dominances of the factors with the solution alternatives to find the optimal one. AHP is carried out in five steps, which is detailed described in [12].

3.2.2 Grey Relational Analysis

GRA builds grey relationships between elements of two series to compare each member quantitatively. One of the series is composed of best-quality entities, while the other series contains comparative entities. The less difference between the two series, the more preferable the comparative series. A grey relational coefficient (GRC) is used to describe the relationship between them and is calculated according to the level of similarity and variability. GRA is usually implemented following six steps, which is detailed described in [13].

3.2.3 Network Selection Using AHP and GRA

In this section we apply AHP and GRA to network selection. The factors that decide the network selection and the relationship among the factors are defined. The whole selection process is presented by model and detailed explanation.

![Figure 2: Flow chart of network selection.](image)

QoS is in the topmost level of the AHP hierarchy for network selection. According to a survey of QoS components in mobile communications [13], the main QoS components in a network are defined as throughput (α), timeliness (β), reliability (γ), security (δ), and cost (ξ), which are in the second level of the hierarchy. In consequent levels, RSS and coverage area are used to present availability. The adoption of coverage area is in order to avoid frequent handoffs for high-speed users. Three parameters, delay (ζ), response time (η), and jitter (θ), decide timeliness. Bit error rate (λ), burst error (ν), and average number of retransmissions per packet (υ) are used to define reliability. In this paper, cellular and ad hoc are considered as available network alternatives (in the bottom level of the hierarchy), and have various parameters in these QoS factors and sub factors.

The network select flow chart is shown in Figure 2. The performances of cellular networks (CN) and multi-hop networks (MN) are evaluated by deciding the differences from the ideal network condition (S₀). Since the effect of each factor on the final goal is different, the formula (1) can be deduced according to [16].

$$\Gamma_{0,c/m} = \frac{1}{\sum_{q=1}^{s} w_q \left| S_{c/m}^q (q) \cdot s - 1 \right| + 1}$$

Where $S_{c/m}^q (q)$ is the normalization of the q-th cellular QoS data or multi-hop QoS data, and $w_q$ is the weight of q-th QoS parameters. The value of $\Gamma_{0,c/m}$ denotes GRC value of CN or MN. The GRCs of CN and MN are compared in the handoff decision maker. The larger the coefficient, the more ability the network has to fulfill the requirements of user and service. Only networks that are able to support the application requirements and necessary mobility features (e.g., stationary, pedestrians, or vehicular) are considered as possible candidates, and subsequently ranked according to their GRC values. If a higher ranked network becomes available as compared to the current one, then a handoff is initiated in addition MT continues
accessing the current network and the algorithm proceeds to section 3.3.

BS before a handoff is initiated, our conservative approach is suited especially for real-time broadband applications.

The evaluation criterion enables a MT to initiate forced handoff in anticipation of a possible crossing of the current cell boundary. $d_1$ refers to the crossover point beyond which a handoff must be initiated in order to complete the handoff process within the $t$ period taken as average handoff time for CN, prior to entering the target network. The calculation of $d_1$ depends on the a priori $t$ and the MT velocity which may vary between successive measurements. The hysteresis value $h$ which triggers the handoff initiation is offline calculated and depends on terminal velocity derived from diversity reception in section 3.2. $h$ also signifies the accuracy with which the MT is able to predict the possibility of a threshold crossing.

4. SIMULATION AND ANALYSE
In this section, an analytical model shown in figure 4 is constructed and then performance of VHO is evaluated and analyzed.

4.1 Analytical Model
As shown in Figure 4, there are 37 BSs and FRSs placed at each shared border of two adjacent cells in the simulation model. We assume that the radius transmission range of a BS is 2000m and a FRS covers an area whose radius is 500m. Each BS has 100 cellular band channels, and by default, each FRS can handle up to 5 cellular band channels using a proper multiplexing technique. In this paper, MVHOM is proposed, in order to verify its validity clearly we hypothesize MT directly connecting to BS or connecting to BS by FRS.

4.2 Evaluating Performance of Vertical Handoff
As shown in figure 5, the call blocking probability (CBP) is studied. With FRSS and not using MVHOM the CBP can be reduced about 3% averagely compared to the case of not using FRSS and MVHOM. While the CBP is reduced no less than 8% averagely, using FRSS and MVHOM. By applying FRSS and MVHOM, the capacity of CN can increase traffic, which implies that the cellular can take additional calls and still keep the acceptable blocking probability.

Figure 6 show that as speed increases, the call dropping probability (CDP) increases. This is because on average the MT requires less time to cross the coverage region of BS/FRS. When the speed is no more than 20 km/m, CDP is effective reduced with FRSS and not using MVHOM. Moreover, the CDP is reduced much further.

It is clear that CMN is able to get better performance in the aspects of reducing CBP and CDP. Our simulation also reveals that the proposal of MVHOM reduces the CBP and CDP effectively.

5. CONCLUSION AND FUTURE WORK
This paper has addressed the key design issues of MVHOM, including location management, network selection, and forced vertical handoff prediction in CMN. The mechanism is

3.3 Forced Vertical Handoff Prediction

Upon completion of section 3.2, the MT determines whether a forced vertical handoff (FVHO) from the serving cell to a neighboring network is imminent. It may be that right after a VHO in section 3.2; the MT finds itself at the edge of the current cell, triggering a FVHO to sustain service continuity. Consequently, the identity of the serving cell depends on whether a handoff was initiated in section 3.2.

Assuming a hexagonal cell structure with sectors (a total of six, as shown in Figure 3.), random mobility (although mobility will be more directional in real life), and constant velocity between successive measurements, a forced handoff is initiated based on the following steps, where the MT:

Step 1 Calculating the sector (as shown in Figure 3.) in which it is located (using the location information gathered from section 3.1 and X-Y coordinates in the serving cell).

Step 2 Deriving the handoff threshold, $d_1 = \tau v$ where $\tau$ is the standard handoff time and $v$ is the terminal velocity.

Step 3 Using an a priori hysteresis margin ($h$), evaluates if a forced handoff needs to be initiated (as shown in Figure 3.), given by $\left| (D - d_1) - d \right| \leq h$, where is the BS/FRS-MT distance estimate at time $t_1$, $D$ is the distance from the center to the midpoint of cell boundary (equidistant for all boundaries), and $h$ is the hysteresis margin. Since $D$ represents the shortest distance from the

![Figure 3: Vertical handoff prediction](image)

![Figure 4: Evaluation Model](image)
constructed using mathematical modeling and computing techniques. In addition results of simulation show that performance (e.g. CBP, CDP) is able to improve effectively by applying with MVHOM.

Though the proposal presented in this paper provide a valuable mechanism for CMN, a lot of work is still necessary in areas of open research. For future research, we will test the proposed mechanism in more comprehensive situations with more network alternatives and selection criteria.

6. REFERENCES

7. ACKNOWLEDGMENTS
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