Mobility Management in Multi-Radio Multi-Channel Wireless Mesh Networks

Ma. Victoria Que* ***Associate Member,*** Won-Joo Hwang** ***Lifelong Member***

ABSTRACT

In a wireless mesh network, there are two types of nodes: mesh routers and mesh clients. These two contradistinct network entities will be characterized and modeled depending on their role in the network. Mesh routers are essentially not mobile unlike the mesh clients. The differences on these nodes should be noted in any protocol design. In this paper, we present a mobility management for wireless mesh network (WMN). This mobility management handles movement of wireless mesh clients as it leaves from a coverage area of a wireless mesh router to another. We consider signaling overhead and mobility as performance metrics.

Key Words : Wireless mesh network, Mobility management, Handoff

Ⅰ. Introduction

A Wireless mesh network has been gaining popularity over recent years. Its features are of tremendous importance over various applications. Wireless networks are beginning to take on a significant role in building automation, industrial process control, and medical systems [1]. The key benefit of using wireless mesh networks is that wireless nodes can be added, relocated, removed or replaced without any complicated network administration. However, this would entail that the system should be able to support for mobility. Mobility of nodes impacts the performance of protocols [2] and it is important that the system can handle it. In WMNs, there are two types of nodes: wireless mesh routers and wireless mesh clients which have different mobility characteristics. The differences of these two should be accounted for and that would require varied treatments on both. Furthermore, in WMN, additional features like multi-radio and multi-channel improvements can be used as advantage for handling mobility. In this paper, we are going to show how we integrate this in our mobility management.

Table 1 summarizes the differences between mesh routers and clients. Identifying the differences and problems among network entities and applying the appropriate solution are the foci of this paper.

This paper is organized as follows. Section II discusses related literature. Section III shows assumptions and the proposed mobility management. Next, we show a performance evaluation on Section IV. Finally, we conclude the paper on Section V.

Table 1. Characteristics of Wireless Mesh Routers and Mesh Clients

	Mesh Router	Mesh Clients
Power	Main Outlet Powered	Battery-powered
Hardware	Complex and more functionalities	Simple
Mobility	Low mobility	High mobility

* 인제대학교 인제공학원 전자정보통신공학과 (tori_q81@yahoo.com)
** 인제대학교 인제공학원 정보통신공학과, 교신저자 (ichwang@inje.ac.kr)
논문번호 : KICS2007-12-569, 접수일자 : 2007년 12월 14일, 최종논문접수일자 : 2008년 2월 27일

Ⅱ. Related Works

Mobility has been studied extensively in different kinds of network. In ad hoc network, usually, the nodes are assumed to have the same mobility pattern. Therefore, all nodes are modeled as somewhat having the same mobility pattern which is usually not true in real world[3]. In WMN, this scheme cannot be applied because of the main differences with ad hoc networks. Studies regarding mobility are often tied up to routing or topology. The mobility of the nodes varies according to its type and can be supported through the wireless infrastructure [1]. A mobility management model that takes advantage of the features of WMN should be introduced. These features include differences among nodes, multi-channel and multi-radio enhancements

Mobility poses undetermined changes in topology and resources and these two should always be the criteria for designing a mobility management model[4,5]. One of the challenges of mobility management, similar to cellular network is to shorten latency[2] and how to provide non-disrupted service even with mobility[4]. Fortunately for WMNs, multiple radios can improve the system in terms of mobility management[6]. Mobility is integrated in topology [7, 10], in routing [8] and in allocating resources [9], because these are the aspects that are greatly affected by mobility. We started with a clustered architecture, since it lessens the impact of mobility to routing [10]

Ⅲ. Proposed Method

3.1 Assumptions

The model involves static wireless mesh routers and mobile wireless mesh clients. Wireless mesh routers should have at least two wireless interfaces. Moreover, they are more powerful compared to the capabilities of mesh clients, in terms of available functions and hardware.

We define a graph G with size m x n with two node types V_{Cn} and $V_{Rn} \in V$ and two types of link E_{Cn} and $E_{Rn} \in E$. V_{Rn} are static, main outlet powered and have Δ multi-radio interfaces and Γ multi-channel interfaces while V_{Cn} are simple and mobile. E_{Cn} is the set of all links between V_{Cn} and V_{Rn} while E_{Rn} is the set of all links that connect V_{Rn}..All V_{Rn} are said to be located evenly in G, that any V_{Cn} can find a nearby V_{Rn} to connect with. V_{Rn} has smooth movement on G, that is, if G is divided into cells, V_{Rn} cannot cross more than one cell at any instant.

For the purpose of this paper, we consider that wireless mesh routers have $\Delta = 2$ radios and the same number of channels Γ wherein one of the channels is assigned specifically for mobility transition messages. There are two types of radio available for wireless mesh routers, one is low power and the other is high power. The high power radio is used to communicate with another mesh router while the low power radio is used to communicate to the mesh clients. Wireless mesh routers are chosen to become clusterheads while mesh clients are the cluster nodes. We aim to formulate a general topology for WMN that would prolong network lifetime and ensure connectivity.

The mobility of wireless nodes can be handled by a handoff process similar to cellular networks. In cellular networks, a mechanism called handoff mechanism is used whenever a mobile node moves out of its home area, similarly on Figure 1. On this section, mobility of wireless mesh clients will be dealt with by a handoff algorithm.

One of the challenges in designing a handoff algorithm is how to minimize handoff latency and signaling load while guaranteeing QoS. Moreover,

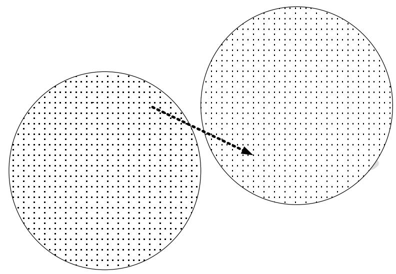


Fig. 1 A mobile node moving away from its home cluster

the mobility pattern of a node cannot be known. For simplicity, we will consider a homogenous system; that is, differences on access technologies and network protocols are ignored. Usual handoff strategies involve dissemination of broadcast messages which usually adds to the signaling load. In addition, the processing time of the clusterhead to make room for an additional clusternode adds to handoff latency. Long handoff time deteriorates the network when the service becomes unavailable during handoff process. We therefore try to minimize the message overhead.

3.2 Signaling Structure

The signaling procedure will be handled by a mobility channel. This channel is a particular channel assigned for this specific task. During handoff, a cluster node would need to know the capability of the new clusterhead and if it allows additional connection and provides the service it needs. The router will broadcast its ROUTER_AD over the mobility channel to its own cluster members and to the nodes in the neighboring clusters each time t_n while the client needs to advertise its own every t'_n. This procedure guarantees service and reduces handoff latency which will be shown later. Table 1 shows the format of advertisements coming from both router(clusterhead) and client(cluster node).

Table 1. Advertisement Format for router and client

ROUTER_AD	CLIENT_AD
CID	ID
Signal Strength/ Weights	Current Clusterhead ID
Services	Demands
Channel	CID

3.3 Signaling Procedure

- All routers/clusterhead will periodically broadcast their ROUTER_AD for each time t_n to the neighboring clusters and to its own cluster.
- All mobile clients/cluster nodes will periodically send their CLIENT_AD for each time t'_n to n clusterheads with the good signal strength and service based from the ROUTER_AD they received. The exact value of n is less than the actual number of clusterheads. A clusterhead that receives a CLIENT_AD will treat it as a pre-handoff message and will do necessary time consuming preparation for the requesting client.
- A client will join cluster based on service and signal strength and will initiate a handoff request for a certain backoff time to avoid unnecessary handoffs. The pseudocode is shown in Figure 2.

It is important to note that we need to refresh the buffer of the clients for the ROUTER_AD every after sending its own CLIENT_AD. Also, time t_n and t'_n are not global timers and can be set per node.

```
HAND-OFF PROCEDURE: PHASE 1
If  (Router && time mod tn == 0 ){
   Broadcast (ROUTER_AD(CID, SS, Service))
}
If  (Client && time mod t'n == 0 && Status == OK){
   Send (CLIENT_AD(CID, ID, Demand, Clusterhead))
}

HAND-OFF PROCEDURE: PHASE 2
If  (Client){
   Send (HANDOFF_REQ(CID, ID, Demand, Clusterhead))
}
Wait
If (Client && HANDOFF_REP == OK){
   Bind (HANDOFF_JOIN(CID))
   Send (HANDOFF_LEAVE_REQ(Clusterhead))
}
```

Fig. 2 Hand-off algorithm

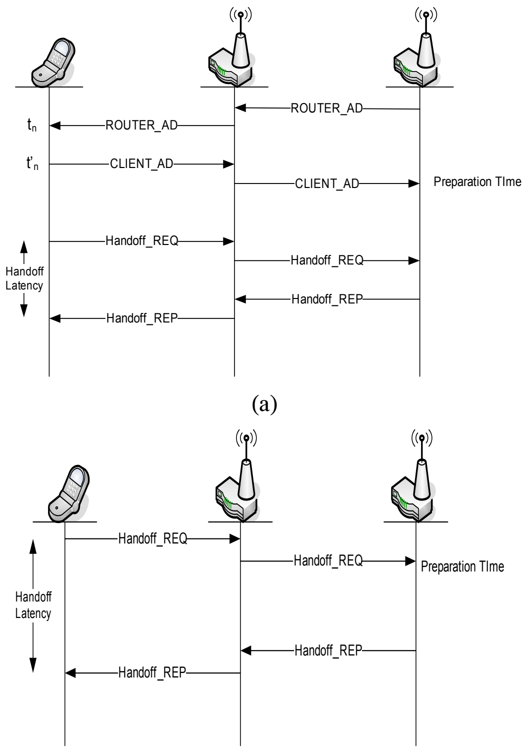
3.4 Synthesis

All the mobility messages will be handled through the MAC layer via mobility channel. As the name implies, this channel is designated for mobility messages. This additional channel enhances the scalability of the system. The router advertises its capability to the nodes belonging to the nearby clusters. Whenever a client node receives an advertisement from a router, it will save it and send a CLIENT_AD on the routers with good signal strength and service. We note that this will be regarded as a pre-handoff message to ensure that

that the preparation time of the future clusterhead will not be a reason for disruption of service and unreliability of the network [4]. Figure 3 depicts this hand-off process. To avoid unnecessary hand-offs, a back-off delay is added for the client.

$$t(n+1)_{request} = (t(n)_{request} + t(n)_{reply}) + B \quad (1)$$

Where $t(n+1)_{request}$ is the time for next handoff request, $t(n)_{request}$ and $t(n)_{reply}$ is the current handoff request and reply while B is the settable back-off time.



(a)

(b)

Fig. 3 Handoff Latency (a) Improved handoff latency (b) Ordinary handoff mechanism with longer handoff latency

3.4.1 Message Overhead

The algorithm poses signaling overhead as it needs to propagate both the clusterheads and cluster nodes advertisements. All these advertisements pass through the clusterhead. The messages sent by the clusterhead over the network are dependent on how often we propagate the messages over the network. Aside from the usual handoff messages from the cluster nodes, a clusterhead needs to broadcast its own status to the nearby clusterheads and an active cluster node needs to inform another clusterhead regarding its status. Unlike on [4], we do not need to propagate the node changes in resource demand to all nearby cluster neighbors. However, we have:

$$M_{CH} = cn_A^{CN}\lambda_{RC}^{CH} + nn_A^{CN}\lambda_{RDC}^{CN} \quad (2)$$

Where :

M_{CH} – the number of messages incurred by the clusterhead

c – number of cluster neighbors

λ_{RC}^{CH} – rate of resources change

n_A^{CN} – number of activenodes

λ_{RDC}^{CN} – rate of demand change

n – neighbors, where in n <c

(2) shows the total overhead messages incurred by the handoff algorithm. The first term is from the router updates which involve the ROUTER_AD being sent to active nodes in the neighboring clusters. The second term is from active cluster nodes as they send CLIENT_AD to n best clusterheads. From [4], the active node is represented by,

$$n_A^{CN} = N\frac{\lambda_{PA}^{CN}}{\lambda_{PA}^{CN} + \mu_{SR}^{CN}} \quad (3)$$

Where :

μ_{SR}^{CN} – service rate

λ_{PA}^{CN} – packet arrival rate

N – number of nodes in a cluster

And we say,

$$\lambda_{RC}^{CH} \propto \lambda_{RDC}^{CN} \quad (4)$$

Since, any change in resource demand from a cluster node will push a resource change on the clusterhead.

Rewriting (2),

$$M_{CH} = cN\frac{\lambda_{PA}^{CN}\lambda_{RDC}^{CN}}{\lambda_{PA}^{CN}+\mu_{SR}^{CN}} + nN\frac{\lambda_{PA}^{CN}\lambda_{RDC}^{CN}}{\lambda_{PA}^{CN}+\mu_{SR}^{CN}} \quad (5)$$

$$M_{CH} = N\frac{\lambda_{PA}^{CN}\lambda_{RDC}^{CN}}{\lambda_{PA}^{CN}+\mu_{SR}^{CN}}(c+n) \quad (6)$$

Comparing (2) to that of [4] the overall message sent by the clusterhead over the network in the algorithm presented is less by a factor of 2. This means fewer messages and client status changes are reported to specific clusterheads. Furthermore, only n_A which is the number of total nodes in the cluster minus the inactive nodes is involved.

3.4.2 Mobility Metric

In a non-GPS system, received signal strength can be utilized to approximate the distance of a node and vice versa. Certain assumptions must be considered:

1. Nodes have isotropic antenna or non-isotropic antenna
2. The nodes are deployed in a static channel meaning signal fading and multipath effects are not considered. This is an important assumption since identifying the location of a node could be very difficult since the variations of the signal can either be because of movement or the dynamism of the channel.

A free space path loss between isotropic antennas is defined as:

$$L_p = \left(\frac{4\pi R}{\lambda}\right)^2 \quad (7)$$

where R is the distance between the receiver and transmitter and λ is the wavelength of transmission. We could determine the received signal strength on every node given by the transmission power of the transmitter:

$$P_R = \frac{P_T}{(4\pi R/\lambda)^2} = \frac{P_T}{L_P} \quad (8)$$

From this, it is easy to see that $P_R / P_T \propto 1/R^2$. Although, it is not reliable to determine the distance using signal strength and with a unity gain, using two successive packet transmissions from a neighboring node, we can approximate the relative mobility between two nodes. We now define the relative mobility of a node v with respect to u_0 by using received signal strength from u_0. :

$$M_v(u_0) = 10\log_{10}\frac{P_{R\_new}^{u_0\to v}}{P_{R\_old}^{u_0\to v}} \quad (9)$$

where $P_{R\_new}^{u_0\to v}$ and $P_{R\_old}^{u_0\to v}$ are the received power detected in u_0 from old and new position, respectively. From (9), a negative $M_v(u_0)$ means that u_0 and v are moving away to each other, while a positive $M_v(u_0)$ indicates that u_0 and v are moving closer to each other. We combine this to the result with other neighbors of v, say u_1, u_2, ⋯; u_m, such that we have:

$$M_v = [E(M_v)^2] = \mathrm{var}_0\{M_v(u_i)\}_{i=1}^{m} \quad (10)$$

A node with high relative mobility variance is more likely to be unstable than the opposite and thus should not be assigned clusterhead. That is the reason we selected wireless mesh routers as clusterheads, because they have low relative mobility variance. A cluster node who had received a ROUTER_AD and sent a CLIENT_AD to a clusterhead could decide whether it needs to proceed on handoff process by estimating movement using (10).

Ⅳ. Performance Evaluation

In the backbone layer, it is important to minimize the amount message overhead to prevent bottlenecks. Here, we compare the handoff algorithm presented with EVL [4] (Expected Visitor Lists) method. The EVL method message overhead increases rapidly as the number of mobile nodes increases. This is mainly because in EVL, all mobile node state changes are being sent to all neighboring clusterhead. Imagine a scenario, where in there are 6 neighbor clusters and at each clusters there are 100 mobile active nodes, at any time, there will be 600 packets being sent at a time by a cluster. Below is a list of parameters on the analysis of control overhead and number of nodes.

Neighbors, c	6
Average number of active nodes/cluster	20
Service rate	1
Resource/demand rate change	1.5
Packet arrival	0.5
n	1~5

It is important that we know how often we should send ROUTER_ID or CLIENT_ID. The graph below, Figure 4, shows the effect of increasing amount of recipients of advertisements. In [EVL], a client needs to send its CLIENT_AD to all neighbors. In our algorithm, we introduced a variable n which could be lower or even equal to the actual number of neighbors. This settable value added flexibility in the scheme, therefore one may have an option to prevent over-flooding the network with signaling messages. Even if $c=n$, the presented handoff mechanism has lower signaling message overhead, as shown in Figure 4.

On the other hand, Figure 5, shows that factor of increase in resource change rate increases the number of overhead by a factor of 2 compared to packet arrival rate which increases by 1.5 only. From this, we could say that sending ROUTER_ID advertisements takes a longer time interval, that is, t_n. This is understandable since mesh routers does not change its state abruptly.

We evaluate the amount of signaling overhead packet in terms of mobility. We vary the mobility of the nodes by changing the rate of handoff transition time from 0-100ms and simulation time is 1000; the result is consistent with our equation which is not dependent on mobility of the nodes. Figure 6 shows the result using different number of neighbors, n.

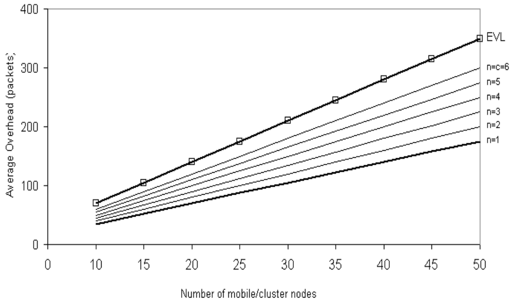


Fig. 4 Effect of increasing amount of recipients of advertisements.

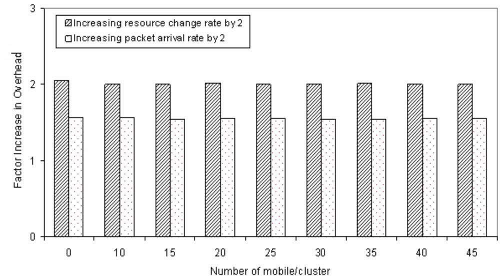


Fig. 5 Factor increase in overhead due to sending ROUTER_AD and CLIENT_AD.

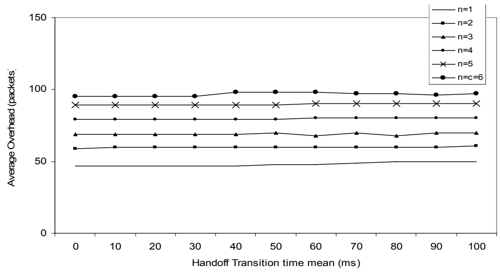


Fig. 6 Average number of signaling overhead with different number of neighbors in terms of mobility.

Ⅴ. Conclusion

In this paper, we develop a handoff mechanism for multi-radio multi-channel wireless mesh network. This provides mobility management over mobile wireless mesh clients. We consider resource and latency as the focus of the paper. We evaluate the proposed mobility management by measuring the overhead incurred by the proposed method. It is shown that compared to another handoff algorithm, the method performs better.

References

〔1〕 I. Akyildizm and X. Wang, "Wireless Mesh Networks: A Survey," *IEEE Communications Magazine*, vol. 43, no. .9, pp. S23-S30, Sep. 2005.

〔2〕 S. Pack et al., "Mobility Management in Mobile Hotspots with Heterogenous Multihop Wireless Links," *IEEE Communications Magazine*, vol.45, no.9, pp.106-112, Sep. 2007.

〔3〕 A. Jardosh et al., "Towards Realistic Mobility Models for Mobile Ad hoc Networks," in *Proceedings of the 9th Annual International Conference on Mobile Computing and Networking*, pp. 217-229, Sep. 2003.

〔4〕 O. Akan and B. Baykal, "Handoff Performance Enhancement with Latency Reduction in Next Generation Wireless Networks," *ACM/Kluwer Wireless Networks Journal*, vol. 11, no. 3, pp. 319-332, May 2005.

〔5〕 M. Que and W. Hwang, "Dual Coalescent Energy-Efficient Algorithm for Wireless Mesh Networks," *Journal of Korea Multimedia Society*, vol.. 10, no. 6, pp. 760-769, June 2007.

〔6〕 P. Bahl et al., "Reconsidering Wireless Systems with Multiple Radios," *ACM SIGCOMM Computer Communication Review,* vol. 34, no. 5, pp. 39-46, Oct. 2004.

〔7〕 J. Wu and F. Dai, "Mobility-Sensitive Topology Control in Mobile Ad Hoc Networks," *IEEE Transactions on Parallel and Distributed Systems,* vol.. 17, no. 6, pp. 522-535, June 2006.

〔8〕 F. Bai, N. Sadagopan, and A. Helmy, "IMPORTANT: A Framework to Systematically Analyze the Impact of Mobility on Performance of Routing Protocols for Adhoc Networks," in *Proceedings of INFOCOM 2003*, vol. 2, pp. 825-835, Mar. 2003.

〔9〕 H. Koyabashi, S. Yu, and B. Mark, "An Integrated Mobility and Traffic Model for Resource Allocation in Wireless Networks," in *Proceedings of the 3rd ACM International Workshop on Wireless Mobile Multimedia*, pp. 39-47, Aug. 2000.

〔10〕 X. Hong et al., "A Group Mobility Model for Ad Hoc Wireless Networks," in *Proceedings of the 2nd ACM International Workshop on Modelling Analysis and Simulation of Wireless and Mobile System*, pp. 53-60, Aug. 1999.

마 빅토리아 께(Ma. Victoria Que) 준회원

2003년 11월 Univ. of the Philippines-Diliman 컴퓨터공학과 학사

2008년 2월 인제대학교 전자정보통신공학과 석사

<관심분야> 무선 센서 네트워크, Ad hoc 네트워크, Cross-Layer 설계

황 원 주 (Won-Joo Hwang) 종신회원

1998년 2월 부산대학교 컴퓨터공학과 학사

2000년 2월 부산대학교 컴퓨터공학과 석사

2002년 9월 일본오사카대학 정보시스템공학과 박사

2002년 9월~현재 인제대학교 정보통신공학과 조교수

<관심분야> 홈 네트워크, 무선 센서 네트워크, 인터넷 QoS, 통신 최적화 이론