Mobile Relay and Group Mobility for 4G WiMAX Networks

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***Abstract*—Relay is one of the key features being considered for IMT-Advanced systems. The relay architectures defined in IEEE 802.16m and 3GPP LTE-Advanced are optimized only for non-mobile relay, i.e., the Relay Station is attached to a designated Base Station and becomes a part of the fixed access network. A mobile relay architecture, where relay may switch attached BS according to operation demand, will promise more resilient relay deployment. In this paper, we first highlight three use cases where mobile relays can offer useful deployment options. Next, we propose an enhanced handover mechanism for relay-based group mobility by extending the IEEE 802.16m specification on relay. To this end, we describe the handover architecture for mobile relay highlighting the C-plane and U-plane enhancements required in order to support group mobility of mobile stations. Using illustration and comparisons, we show that mobile relay will offer significant benefits of signaling overhead reduction and provide users seamless mobility experience compared to fixed relays.**

***Index Terms*—IMT-Advanced, IEEE 802.16m, Relay, Mobility, Overhead Savings.**

I. Introduction

"INTERNATIONAL, Mobile Telecommunications - Advanced (IMT-Advanced) systems are mobile broadband communication systems that include new capabilities that go significantly beyond those of the IMT-2000". The key requirements of IMT-Advanced systems include *increased spectral efficiency and bandwidth, improved cell edge performance and mobility support, reduced Control and User plane latency, reduced handover interruption time* [3]. IEEE 802.16m (next generation WiMAX networks) and 3GPP LTE-Advanced are considered to be the top candidates for satisfying and in certain cases, even exceeding the IMT-Advanced requirements. Both technologies consider advanced features such as carrier aggregation, coordinated multipoint processing (CoMP), relays as potential solutions towards achieving IMT-Advanced requirements. With cell sizes shrinking drastically owing to the need for higher spectral reuse, the number of pico and femto base stations that are deployed is growing very high thereby increasing the deployment costs. Relays, which possess wireless backhaul links to the core network through BSs can significantly reduce the deployment costs while providing capacity and coverage comparable to pico and femto BSs [6]. Other factors such as lower equipment cost, easier site selection together have motivated the wireless service providers, equipment vendors as well as the academia to focus on enhanced relay solutions.

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While fixed relays support several use cases defined in the standards, mobile relays can enable more use cases that are not part of the standards yet. We identify that mobile relays can address the key requirements of low latency and handover interruption time, high spectral efficiency. Prior work on enhanced relay solutions primarily consider multi-hop and cooperative relays but very few take into account the impact on the standards. Similarly, IEEE 802.16j relay standard supports relay mobility. Although, its implementation/deployment is largely limited as it fails to reduce the relay station complexity and has backward compatibility issues with 802.16e [2]. We believe that the mobile relay solution we propose is unique in the way that it provides backward compatibility with legacy systems while providing significant gains in the performance. We summarize the main contributions of our work as follows:

- We highlight three important use cases, where mobile relays have the potential to provide performance improvements under high speed user mobility, heavy load conditions.
- We propose an improved handover mechanism for mobile relays with a strong view of the current relay architecture in the IEEE 802.16m standards. Based on this handover procedure, we describe the relay handover architecture for 16m Advanced Relay Station. We highlight the Control plane and User plane architectural enhancements required to support relay mobility.
- We carry out a performance comparison of mobile relays against "no relay" and "non-mobile relay" scenarios mainly using key parameters such as overheads on the radio and network interfaces which underline the advantages of our proposed solution.

The rest of this paper is organized as follows. Section II presents an overview of relays with respect to the cellular paradigm following which use cases for mobile relays are discussed. In Section III, a brief overview of the IEEE 802.16m relay architecture for the control plane and user plane is provided. In Section IV, an improved handover mechanism for the relay station from one serving base station to another is proposed following which the mobile relay architecture is presented. The C-plane and U-plane architectural enhancements required for the functioning of the mobile relay are

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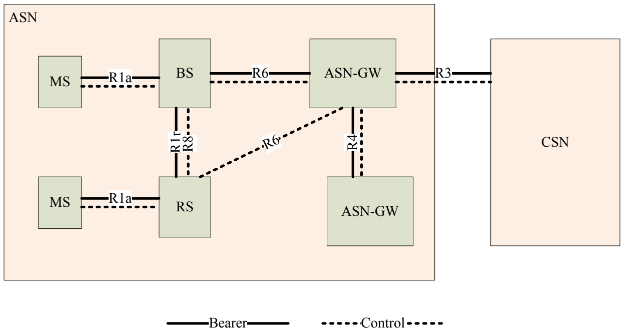

Fig. 1. IEEE 802.16m Interface Architecture for Relay Station

defined. Section V focuses on the performance comparison of the handover mechanism for mobile stations in three different scenarios. The analytical results are presented in the form of overhead comparison. Finally, in Section VI, the conclusions are summarized.

II. Mobile Relay Overview

A. Overview of Relays in the Cellular Network

Relays are considered as enhancements for the traditional cellular architecture. Relay Stations can intelligently relay data between the BS and mobile stations wirelessly. The communication between the BS and RSs takes place in a similar way as the communication between BS and MSs using point-to-multipoint (PMP) connectivity. In other words, the RS(s) maintains a wireless backhaul connectivity with the BS and hence the network. At the other end, the RS can establish PMP connectivity with the MS. Therefore, the RS can provide both uplink and downlink connectivity for the MS. The BS-RS links and RS-RS links are usually referred to as relay links whereas the BS-MS links and RS-MS links are referred to as access links.

Relay Station proves beneficial in several ways in the cellular network. First, RS provides increased capacity by increasing the frequency reuse. In other words, capacity increase can be realized when both BS and RS in a given area communicate with different MSs using the same frequency resources. Second, it can provide improved coverage with lesser deployment costs as against femto BS from the fact that relay uses wireless backhaul link with the network. This facilitates adhoc deployment of relays in areas where the BSs cannot provide sufficient coverage (cell edge, shadows). [6] illustrates several deployment scenarios for relay station.

B. Use Cases for Mobile Relay

The key features of relays such as low equipment cost and flexible deployment options has resulted in strong interest from the industry as well as academia to focus on relay mobility. More intriguing is the fact that mobile relays can potentially be leveraged to achieve new levels of seamless user mobility experience. We highlight three important use cases for leveraging mobile relays to realize some key IMT-Advanced requirements. These use case are discussed as follows.

1) Group Mobility: First, we highlight group mobility where an improved handover mechanism enables seamless mobility of a group of users. Group mobility makes sense for concurrent handovers to be performed for a group of users in high speed vehicles such as trains, buses. The idea is to have a mobile relay station in the high speed vehicle serving the MSs within. Mobility results in a handover of the relay station to a neighboring BS. At the same time, from the perspective of the MSs, the point of attachment, i.e., RS remains the same. Hence, the PMP connectivity for the MSs is preserved while the RS handover procedure is performed transparent to MSs. Group mobility can significantly reduce the overheads on the radio interface and network thus minimizing latency for all users. In addition, this improved handover mechanism can significantly reduce the HO interruption time which is one of the key requirements for IMT-Advanced systems.

2) Reliability: The mobile relay concept can also be applied to improve relay network reliability. Since RS is attached to the core network with relay link as wireless backhaul, its reliability is less than typical wired backhaul. Reliability may be a major issue for low-cost small-cell RSs. Ideally, radio link failure prevention and recovery at RS should be handled transparent to the attached MSs. With the mobile relay framework, an RS that is about to experience or just experiences radio link failure on relay link is capable of re-establishing backhaul connection with another suitable neighbor BS using a handover procedure, and this just appears as a scheduling glitch for all MSs associated with RS. Therefore, such self-healing wireless backhaul operation significantly improves network reliability without incurring any special handling at MS.

3) Wireless Backhaul Load Balancing: Similar to the use case of enhancing relay network reliability, the network may even more aggressively switch point of attachment for the RS based on operation status, such as loading of different BS and the associated network gateway. The network may initiate handover for RS to a more suitable BS to ensure load balancing within radio access network as well as core network. Again with mobile relay framework, the network can dynamically perform such operation without impacting the connectivity of MSs associated with the RS. This provides a very attractive feature for network operators.

III. Relay Architecture Overview

A. IEEE 802.16m Relay Architecture

A non-transparent relay standard has been specified by IEEE 802.16m wherein the advanced relay station (ARS) has the features of distinct physical layer cell IDs in each of the sectors it controls. The 16m Relay functions using the "decode and forward" paradigm where an ARS controls its own cell with a wireless backhaul connection to the access service network gateway (ASN-GW) through the advanced base station (ABS). 802.16m supports both time-division duplex (TDD) as well as frequency-division duplex (FDD) modes for relaying.

Fig. 1 shows the interface architecture of a 16m relay [5]. It can be observed that there are several reference points that define the protocols and procedures between the different entities of the 802.16m system [7]. $R1$ interface provides radio link between base station and mobile stations. $R6$ and $R8$ reference points provide the ABS ⇔ ASN-GW and ABS ⇔ ABS interfaces respectively. $R3$ reference point provides IP connectivity for the ASN-GW from the Connectivity Service Network (CSN). The Relay Station incorporates both ABS as well as AMS functions. The AMS part of the relay station has an $R1r$ interface with the ABS whereas the ABS part of the relay station has $R8$ and $R6$ logical connections with the ABS and ASN-GW respectively. The ARS ⇔ AMS PMP connectivity is provided by the ABS part of the relay station using $R1a$ interface. The relay station uses $R6$ interface to communicate with the ASN-GW. Since there is no physical link between the relay station and the ASN-GW, the relay uses the two hop ARS ⇔ ABS ⇔ ASN-GW physical link to communicate with the network. The access and relay $R1$ links are referenced using the notations $R1a$ and $R1r$ respectively to underline their functional difference. One of the key features of the IEEE 802.16m Relay architecture is that the relay station implements all the control mechanisms of the associated mobile stations such as handoff, security, idle and sleep operations, etc.

Fig. 2 shows the C-plane protocol architecture. On receiving the control messages from ASN-GW over $R6$, the ABS performs classification to recognize that the received ASN packets are ARS (the ABS part) related control messages. The ABS, then, translates the control messages between the two interfaces by encapsulating them in a "MAC-L2-XFER" MAC management message and sends it to the target ARS with $Flow\,ID = 1$ [1]. Similarly, on the uplink, the ARS sends the control message as MAC-L2-XFER message with $Flow\,ID = 1$. On the relay link, MAC Control PDUs are used for control message exchange between ARS and ABS. The $R8$ control messages between the ABS and ARS, similarly, are transferred as MAC-L2-XFER messages over the physical $R1r$ link.

Fig. 3 shows the U-plane protocol architecture. The GRE tunnels running from the ASN-GWs are terminated at the ABS. The AMSs related packets are then detunneled and encapsulated into a relay MAC PDU (MPDUs) of the ARS where the advanced relay forwarding extended header (ARFEH) may be appended to identify the ASN data traffic. The relay MPDUs encapsulated with the ARFEH header is indicated by GRE* in the figure. The mapping between the GRE tunnel IDs and ARFEH headers is maintained both at the ABS and the relay station so that the $R6$ data function effectively is running between ARS ⇔ ABS ⇔ ASN-GW. The ARS decapsulates the received relay MPDU and transmits the ASN data traffic to the target AMSs as AMS MPDUs. Similarly, on the uplink, the ARS encapsulates the data traffic from different AMSs into a relay MPDU. Again, the ARFEH may be appended to identify the ASN data traffic. Finally, the ABS maps the data packets to the AMS specific GRE tunnel that runs from the ABS to the ASN-GW.

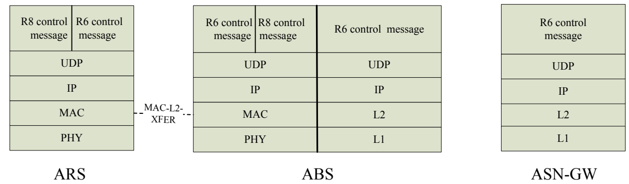

Fig. 2. IEEE 802.16m C-plane protocol stack for relay support

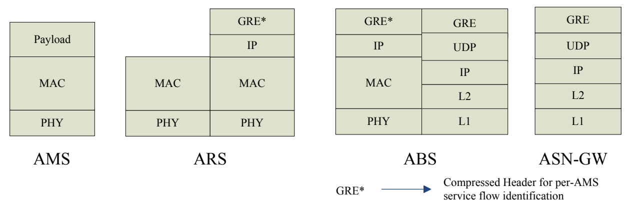

Fig. 3. IEEE 802.16m U-plane protocol stack for relay support

IV. Support for Mobile Relay

The mobile relay solution we propose in this paper can be leveraged for the use cases described in Sec. II. As mentioned in Sec. II, the essence of mobile relay solution lies in maintaining PMP connectivity with the AMSs, while performing network operations to re-establish the backhauling Control and User plane transparent to the AMSs. We describe methods to enable mobile relay with the existing relay architecture in IEEE 802.16m.

A. Relay Station Handover Mechanism

First, we focus on the handover (HO) procedure for the mobile relay between the serving and target ABSs. For simplicity, we only consider intra-ASN handover in this paper. The handover mechanism is illustrated in Fig. 4.

The handover and network re-entry process flow for ARS is as shown below:

1) Obtain Network Topology and neighbor ABS parameters
2) Initiate ARS handover to target ABS (either ARS or ABS initiated)
3) Perform network re-entry at target ABS
4) Configure Operational Parameters

Except for the final step, where the ARS needs to obtain the configuration to provide PMP connectivity to the AMSs, the handover framework of ARS closely resembles the handover procedure for a regular mobile station. The handover and network re-entry procedure takes place in two phases - 1) Handover Initiation and Preparation Phase 2) Handover Execution and Network Re-entry Phase.

1) Handover Initiation and Preparation Phase:

- The ARS sends a Handover Request Message with a list of preferred target base stations to the serving ABS.
- The serving ABS, in turn, sends an $R8$ Handover Request message to the target ABS(s).
- The target ABS(s) obtains AK Context and initiates data path pre-registration for the ARS with the ASN-GW over $R6$. The target ABS also classifies the Handover Request message to identify that handover is required for a relay station.

- If handover for the ARS is accepted, the target ABS must send an $R8$ Handover Response message to the serving ABS. But the target ABS needs the tunnel mapping information to perform GRE Tunnel ID $\Leftrightarrow$ ARFEH mapping to identify the per-AMS ASN tunnels and their corresponding QOS parameters. *Hence, the target ABS should piggyback a Tunnel Mapping Context Request message requesting the tunnel mapping table and per-tunnel QOS over the Handover Response message.*
- The serving ABS sends a Handover Command message over the relay link to the ARS to inform the ARS about the handover decision.
- The ARS starts ranging at the target ABS to begin the network re-entry procedure. For optimization, if the HO-Reentry-Mode is set to 1 in the Handover Command message sent to ARS, the serving ABS can ensure that data path is available for the ARS related AMSs until the ARS completes network re-entry at the target base station.

2) Handover Execution and Network Re-entry Phase:

- The ARS initiates the Ranging Request/Response message exchange with the T-ABS.
- A Handover Confirmation message is received by the target ABS from the serving ABS. This message includes the piggybacked *Tunnel Mapping Context Response* message so that the target ABS can perform data path pre-registration with the ASN-GW over $R6$. The ASN-GW may either set-up a brand new tunnel with the target ABS for the corresponding service flow and break the GRE tunnel with the serving ABS; or it may reuse the same GRE tunnel for the service flow and update its Tunnel forwarding port to be the target base station. The latter case is straight forward where the ARS can establish data path directly with ARS during its re-entry. In the former case, the target ABS needs to perform Data Path Reg/Update with the ARS over $R8$ for the ARS to update the new tunnel mapping context. The data path registration procedure ends when the target ABS receives a Path Registration Response message from the ARS.
- For the ARS to support relay operation at the new serving ABS, a Layer-3 control path from the ASN-GW to the ARS is also established to update configuration from the OAM (Operations, Administration and Maintenance) server.
- The serving ABS, after sending the Handover Confirmation message may discard all connections resource information (ARS and related AMSs) including the MAC state machine and all outstanding buffered PDUs.
- The Handover Complete message from the target ABS indicates the completion of Network Re-entry which prompts the serving ABS to release all MAC context and MAC PDUs associated with ARS. Following this, the serving ABS initiates Data Path De-registration with the ASN-GW.
- Finally the ARS receives the PHY layer operational parameters from the target ABS. Any changes in the operational parameters are communicated to the AMSs by the ARS over the access links.

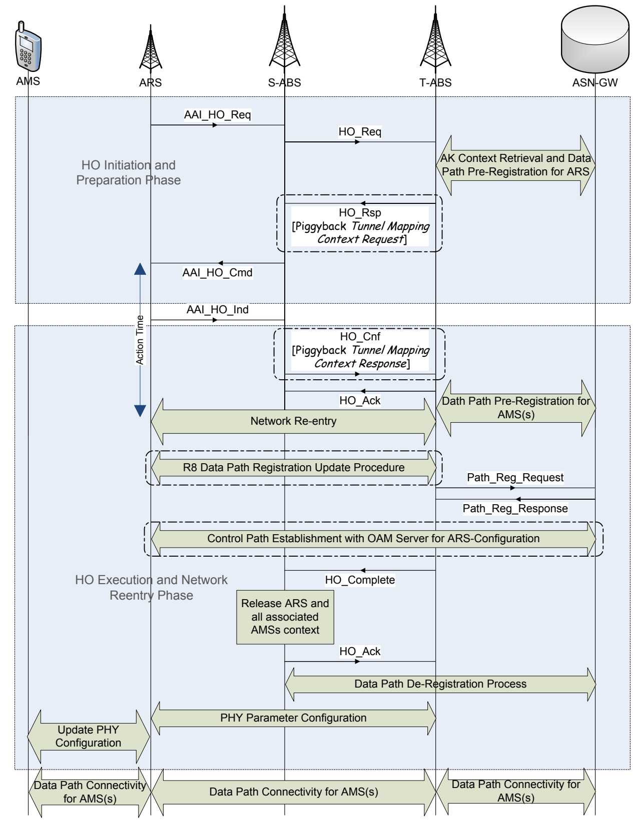

Fig. 4. Improved Handover Mechanism to enable Group Mobility

B. Re-establishment of Relay Station Wireless Backhaul

The handover architecture for a mobile relay is illustrated in Fig. 5. The serving base station maintains a table containing the mapping between the ARFEH ID and the GRE tunnel ID for each of the per AMS service flows. The figure shows a sample table entry that needs to be exchanged between the base stations during ARS handover. MS Info [=AMS1] includes AMS information such as MSID, service flow info. DP ID [=5B9F9C71] is the 32-bit Data Path identification for the per AMS GRE Tunnel. ARFEH ID [=8FE] is the compressed 12-bit identification for the per AMS service flow between base station and relay station. QOS parameter [=X] contains the QOS description of the service flow.

On the Control plane, the Tunnel Mapping Context Request/Response over $R8$ helps the target base station to perform Data Path Registration for ARS associated AMSs. The target performs Data Path Pre-Registration Procedure with the ASN-GW. Here, we assume the more common case where the ASN-GW establishes a new GRE tunnel [=A70BF54C] with the target base station for each of the service flows and breaks the GRE tunnels with the serving ABS. The target base station assigns a new ARFEH [=D84] for these per AMS tunnels for identification. The target ABS also needs to perform Data Path

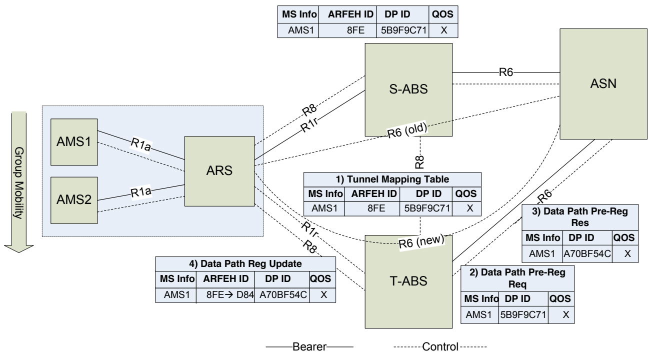

Fig. 5. Mobile Relay Handover Architecture

Registration Update with the ARS over $R8$ for the ARS to update the new tunnel mapping table with the ARS. To enable OAM Configuration at the relay station, a Layer-3 control path is established between the ASN-GW and the ARS.

On the U-plane, the ASN-GW establishes new per AMS GRE tunnels with the target base station. Once the appropriate tunnel mapping is achieved, data path is established with the relay station. For out-of-band relays, the data path from ASN-GW to the AMSs through the serving ABS is maintained until the network re-entry is complete. For in-band relays, advanced handover mechanisms [4] such as Entry-Before-Break can ensure that this path is available until the completion of network re-entry. After data path registration and L3 Update from the OAM server, the end-to-end data paths from the ASN-GW to the AMSs are restored through the target base station and relay station. Thus we could observe that the entire handover procedure has been made transparent to the AMSs.

C. Radio Link handling for Seamless In-band Relay Mobility

One of the important aspects of mobile relay is to re-establish a wireless backhaul between relay station and the target base station transparent to the mobile stations. We have assumed that the relay station maintains a logical connection with mobile stations during ARS handover. Although for in-band relay mobility case, the AMS may experience "Radio Link Failure" if the relay station handover procedure takes longer time duration. Therefore, the relay station should be notified in the *Handover Command message* of the super-frame structure used by the target base station for the Access and Relay links before handover for ARS takes place so that

- The RS knows the relay zone sub-frames used by the target BS so that it can synchronize its Relay Zone configuration with the target BS to acquire the target BS.
- The RS may continue RS mode operation with the MS using the appropriate Access Zone sub-frames.

Alternatively, the ARS may be notified by the serving ABS about the target ABS frame structure during the handover procedure using $R8$ messages or directly from the OAM server before handover. The detailed mechanism to enable the above procedure is out of scope of this paper.

V. Performance Evaluation

We compare the performance of mobile relay with "relay with no mobility support" and "no relay" scenarios. For each of these three scenarios, we perform a comparison of overheads on two levels, the air interface and the network. On the air interface, overheads on $R1a$, $R1r$ including $R6$, $R8$ logical links are considered. On the network side, $R6/R4$ and $R8$ overheads are considered for comparison.

For the "*No Relay*" scenario, all the mobile stations need to perform handover from the serving base station to the target base station in the absence of relay station. For the "*Relay with no mobility support*" case, first, the relay station has to perform handover of the AMSs to a target base station. Then, it performs de-registration with the serving base station. Once again, when the relay station resumes normal functionality by establishing wireless backhaul with the network, the AMSs will be able to attach to the ARS by performing the routine handover procedure. Hence the overheads are three-fold in this case; handover of AMSs to a target ABS, backhaul connection re-establishment for ARS, AMSs handover back to ARS. Finally, for the "*Mobile Relay*" case, only the relay station performs handover from the the serving base station to the target base station. After the completion of network re-entry, ARS receives the configuration from the OAM server. Similarly, the target base station updates the PHY configuration at the relay station, which in turn, may update the PHY configuration with the AMSs over the access link.

We consider the overheads due to the mobility of N mobile stations. The number of control messages is scaled for N users. The different Radio and Network Overheads are listed in Table I and II. On the air interface, it is very clear that "mobile relay" scenario requires negligibly small number of control messages for handover to take place, especially, as N becomes large. On the network side, again, the overheads are reduced considerably in the case of mobile relay. The establishment of Layer 3 connectivity with the OAM server to configure the ARS as a base station may contribute to overheads but hardly has any impact on the latency. Hence, it becomes less relevant. Fig. 6 and Fig. 7 compare the overheads for the case when $N = 100$. As an optimization for mobile relay, the serving ABS may also perform de-registration for all ARS-related AMSs in one step. This is possible since the serving ABS is capable of classifying the GRE tunnels that correspond to ARS-related AMSs. Thus, overall, we can observe that mobile relay results in significant overhead reduction both on the radio interface and the network. This also essentially means that the handover latency is largely reduced thereby providing seamless mobility experience for high speed users.

VI. Conclusions

We have analytically shown that mobile relays provide significant performance improvements over the current relay standards of IEEE 802.16m. Moreover, by defining three use cases, we have shown that mobile relays have several implementation options attractive for the operators to provide

TABLE I
COMPARISON OF RADIO OVERHEAD FOR AMS HANDOVERS

Radio Overheads	No Relay	Relay with no mobility support	Mobile Relay
Ranging Procedure	N	$(2*N)+1$	1
Privacy Key Management	N	$(2*N)+1$	1
MAC Handover Signaling	N	$(2*N)+1$	1
PHY Parameter Configuration	NA	Required	Required
Data Path Reg Update	NA	NA	Required

TABLE II
COMPARISON OF NETWORK OVERHEAD FOR AMS HANDOVERS

Network Overheads	No Relay	Relay with no mobility support	Mobile Relay
R8/R6/R4 Handover Signaling	N	$(2*N)+1$	1
Data Path Reg Procedure	N	$(2*N)+1$	$N+1$
Data Path De-Reg Procedure	N	$(2*N)+1$	$N+1$
AK Context Transfer	N	1	1
CMAC Key Count Update Procedure	N	1	1
Tunnel Mapping Context Exchange	NA	NA	Required

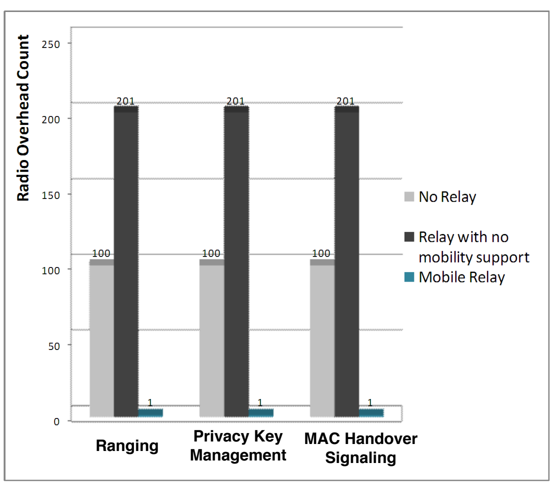

Fig. 6. Radio Overhead Comparison for $N = 100$

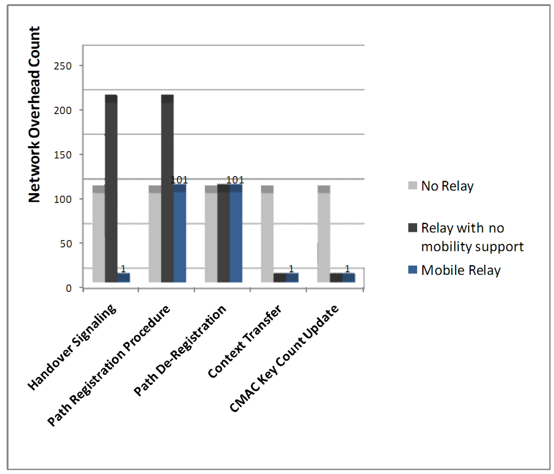

Fig. 7. Network Overhead Comparison for $N = 100$

extended coverage and high speed mobility support. With such features, we foresee mobile relay as one of the key feature enhancements for IMT-Advanced system. In addition, we would like to use this study to motivate further studies towards additional relay enhancement features such as multi-hop relay, client relay, cooperative relay and mesh relay built upon 4G cellular network architecture. Mobile relay along with other relay enhancements are promising technologies for better network performance, broader applications and more satisfying mobile computing experience. Such features provide great opportunities for both wireless business and research.

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