Group Mobility Management for Vehicular Area Networks Roaming between Heterogeneous Networks

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Abstract—**Due to widespread deployments of Vehicular Area Networks (VANs) and the increasing affordability of mobile data and smart mobile devices, there is an increasing demand for accessing applications and services on-the-go. As a result, group mobility scenarios have emerged, especially over VANs on public transport networks (e.g., buses, trains, aircraft, and so on). Therefore, when a group of users roam as a single unit, the NGMN must be equipped with efficient route optimization and group mobility management support. In light of this, the Internet Engineering Task Force (IETF) has defined the NEtwork MObility (NEMO) basic support protocol for location transition management for a group of members moving between two networks. Nevertheless, IETF's group mobility management solution is limited to homogeneous networks. Therefore, this paper proposes the integration of NEMO support for NGMN architectures for enabling group mobility management among multiple heterogeneous networks. Further, according to the evaluation and results, it is also capable of successfully handling handoff and mobility management for complex nested mobility scenarios.**

Keywords-NEMO; Network Mobility; MIP-NEMO; SIP-NEMO; IMS; UMTS; WiMAX; SIP; Mobile IP

I. INTRODUCTION

The demand for data and service access on-the-go is rapidly increasing with the expansion of the Next Generation Mobile Network (NGMN). With commuters travelling on public transportation systems (e.g., buses, trains, ships, and aircraft) trying to access these applications and services group mobility scenarios are emerging. Therefore, commuters with individual mobile devices or Personal Area Networks (PAN) travelling in a Vehicular Area Network (VAN) (e.g., on a transportation carriage) can be considered as a moving network or a mobile network [1]. This will enable all mobile devices on board a mobile network to achieve global connectivity via one or more special gateway routers. In such a scenario, the mobile network is considered to be multi-homed since there are multiple interfaces connected to the Internet through one or more of these mobile routers.

As the mobile network roams via heterogeneous networks, the mobile router should ideally provide uninterrupted service connectivity for its clients, irrespective of the access technology or network that is being used. Therefore, it is essential for efficient group session handoff and group mobility management mechanisms to be in place for collectively providing seamless service access for nodes of a mobile network. For a group of mobile nodes commuting between homogeneous networks, location transition management was initially addressed by the Internet Engineering Task Force's (IETF) NEtwork MObility (NEMO) basic support protocol by defining an extension to Mobile IP v6 (MIPv6) [2]. However, the main setback of MIPv6-NEMO was that it encountered sub-optimal routing as a result of bi-directional tunneling [3]. There is also the increasing likelihood where some commuters may have PANs nested within. In the case of PANs which are nested within a mobile network, as the number of nested levels increase, data routes depart more and more from the optimal. This leads to another multi-angular routing issue called pinball routing, which contributes to latency and increased packet size for each level of nesting [4].

Therefore, in response to the problems of MIP-NEMO, a Session Initiation Protocol (SIP) based version of NEMO is proposed [4]. The main advantage of shifting network mobility management to the Application Layer is that it can overcome the route optimization problem by reducing the pinball routing effect and hence reduce the handoff delay even for complicated nested mobility scenarios. Despite its importance, the potential of integrating SIP-NEMO for enabling network mobility and route optimization for interworked heterogeneous networks has not been fully exploited as yet. Initial works on this area are published in [5], where the authors' introduce a SIP-NEMO based group session management platform for the NGMN. This article further contributes by extending that work for supporting seamless session handoffs for PANs travelling in a VAN creating a nested mobility scenario. The remainder of this paper is organized as follows. Firstly the concepts of SIP-NEMO assisted mobility management are explained. Next, the integration of SIP-NEMO to the NGMN is presented, where three scenarios of network mobility are discussed. Thereafter, the simulation results and validation are presented prior to the concluding remarks.

II. SIP ASSISTED GROUP MOBILITY

Two main solutions have been proposed at different layers for seamless session forwarding and data routing for a multi homed, roaming mobile network [6]. As previously mentioned, the IETF's initial approach was MIPv6-NEMO operating at the Network Layer [2]. Despite the fact that it reduces the signaling cost related to location updates and the complexity of handoffs, the use of MIPv6 introduced many shortcomings

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This work is partly supported by the Australian Research Council under the Discovery Project Scheme (DP1096276).

978-1-4244-3574-6/10/$25.00

such as sub-optimal routing, increased path lengths, and packet header overheads due to bi-directional tunneling [3]. In response to this, a SIP based network mobility management and route optimization scheme named SIP-NEMO is proposed at the Application Layer [4].

The SIP-NEMO protocol is essentially an extension of the well known SIP protocol, thus giving SIP clients the freedom for easily roaming between networks. It achieves route optimization by translating the SIP header. As per the illustration in Fig. 1, the main element in such a SIP enabled roaming mobile network is the SIP Network Mobility Server (SIP-NMS). A given SIP-NMS has a corresponding SIP Home Server (SIP-HS). As the mobile network roams between networks (e.g., from UMTS to WiMAX), the on board SIP-NMS negotiates a new point of attachment/address via the new SIP Foreign Server (SIP-FS). Next, the SIP-NMS recovers all ongoing sessions and informs the SIP-HS about its new location via the new point of attachment/address. In which case, the SIP-NMS acts as the gateway for the roaming mobile network.

The SIP-NMS ensures that all attached nodes are globally reachable and maintain their current data flow as the mobile network changes its point of attachment. This is achieved by translating a SIP-REGISTER request. Hence, the mobile network's changing of its point of attachment or moving from one subnet to another is transparent to its onboard nodes. The corresponding SIP-HS is informed of its new location (point of attachment) as and when a SIP-NMS attaches to a new network. The SIP-FS, which is fundamentally a SIP Back-to-Back User Agent (B2BUA), plays an important role by providing a Uniform Resource Identifier (URI)-list service, which reduces signaling cost and handoff delay as a result of optimized routing [7]. As the mobile network roams, its SIP-NMS collects the source and destination addresses of all its ongoing SIP sessions into a SIP-URI list. This SIP-URI list is embedded into the SIP ReINVITE request and forwarded to the SIP-FS of the newly attached network. When the SIP-FS receives the SIP ReINVITE request with a URI list, it individually generates SIP ReINVITE requests for all data sessions that need to be handed-off and re-routed to the new network. This paper also shows that SIP header translation for route optimization works best under complex levels of nesting. Furthermore, SIP-NEMO can also provide route optimization when two SIP clients are in the same mobile network even if the mobile network has a complex nested level of routing as described in [4].

III. GROUP MOBILITY MANAGEMENT IN THE NGMN

The aim of this work is to use SIP-NEMO protocol for group and nested group mobility in a VAN. To the best of our knowledge, the only noteworthy initiation made towards this is available in [8]. Nevertheless, the solutions discussed in [8] fail to guarantee seamless session continuity [9]. As previously mentioned, our earlier work introduces a basic platform for SIP-NEMO based group mobility [5]. This paper further extends our work for more complex nested mobility scenarios that arise in VANs.

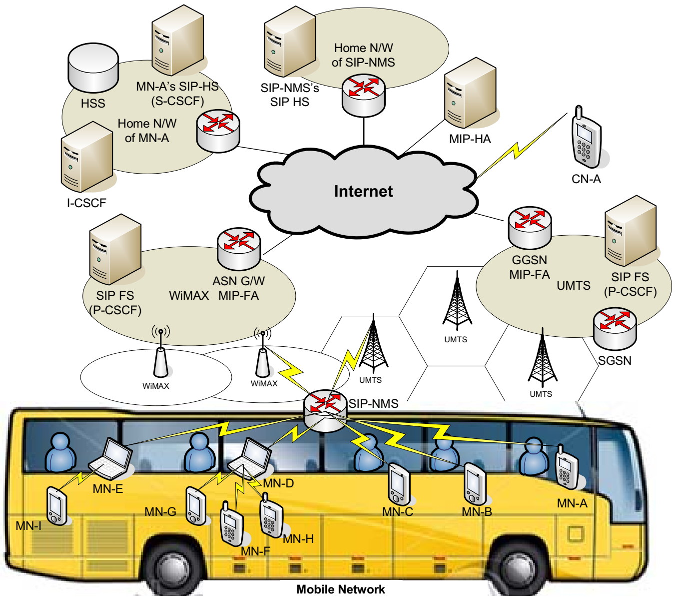

Figure 1. SIP-NEMO assisted Group and Nested-Group Mobility.

The SIP-NEMO implementation is based on a well cited NGMN platform accepted by both the industry and academia [10]. All networks are loosely coupled for data routing and tightly coupled via the IP Multimedia Subsystem (IMS) for session control signaling [11]. Therefore, the session mobility management for a group of users (or a mobile network) can successfully be achieved by introducing SIP-NEMO into the IMS as illustrated by Fig.1. The SIP B2BUAs in each network, which are also Proxy-Call Session Control Functions (P-CSCF) of the IMS, are modified for handling the URI list service. With this modification, the P-CSCF can now function as a SIP-FS to a SIP-NMS that may roam into its network, thus easily being able to handle network mobility. Therefore, the SIP-NMS acts as a Network Address Translator (NAT) for the mobile network's clients trying to connect to the IMS. Then again, the SIP-NMS also appears as a roaming SIP user from the SIP-FS's point of view. Each SIP-NMS also has its corresponding SIP-HS.

A. *Network Mobility*

As the mobile network, which consists of onboard mobile nodes roams from WiMAX to UMTS, the SIP-NMS must first recover its global reachability. Therefore, the SIP-NMS must obtain an IP address for its UMTS interface and ReINVITE all ongoing sessions via the UMTS network. Fig. 2 illustrates the related signaling flow. Similar to the previous explanation, firstly the standard UMTS attach and PDP context activation procedures are performed by the SIP-NMS. In order to guarantee terminal mobility, MIPv4 is implemented at the Network Layer. The actual IP address allocation for the SIP-NMS is initiated by sending the MIP registration request to its MIP-HA via its MIP-FA, which is the Gateway GPRS Support Node (GGSN) in this case [12]. Followed by this is the exchanging of a MIP Binding Update message between the

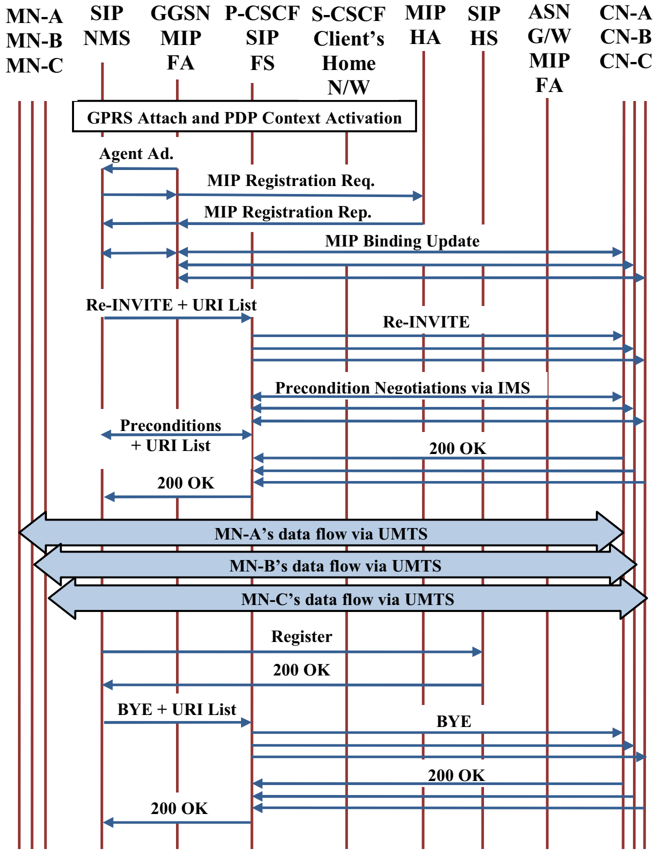

Figure 2. Signaling Flow for SIP-NEMO associated Network Handoff.

SIP-NMS and its existing SIP destination clients for avoiding triangular routing [13].

Then the SIP-NMS sends a ReINVITE request with a URI list to the P-CSCF, which is also the SIP-FS, in order to recall the ongoing SIP sessions. Then the P-CSCF reproduces individual INVITE messages to all CNs. After each SIP CN receives the ReINVITE request according to the URI list, resource/precondition reservations for the UMTS interface will initiate for each of these sessions. Individual precondition negotiation is vital since some clients/applications require certain preconditions (that is, QoS levels) to be met before handing-off a session. Now the SIP-NMS is ready for proceeding with the session flow via the new network. The point to note here is that, the SIP-FS combines all responses received by destination clients in the URI list to a single message and forwards it to the SIP-NMS. Hence the session handoff signaling overhead is considerably reduced. After the precondition reservations, each CN will resume the ongoing sessions via the new contact address of the SIP-NMS.

Subsequently, a REGISTER request is sent to the mobile network's SIP-HS by the SIP-NMS. The reason being that, as the SIP-NMS attached mobile network roams into the UMTS network, the new location information (i.e., the IP address) must be updated with its SIP-HS. Note that this does not involve the IMS since it is handled by the NEMO architecture. Once the SIP-HS responds with a 200 OK message, the SIP-NMS attached mobile network will be globally reachable (via the UMTS network). Finally, the breaking of the session via the WiMAX network takes place by using the URI list service.

B. Nested Network Mobility

As mentioned earlier, Fig. 1 also illustrates the possibility where there may be a PAN nested within a given mobile network. Assuming that a PAN is also another SIP based mobile network, the SIP-NMS of the PAN will now become a sub-SIP-NMS of the parent-SIP-NMS of the parent mobile network. In this case, the sub-SIP-NMS must first register itself with its parent-SIP-NMS and ReINVITE all ongoing sessions before handoff and setting up the new data routes. Firstly, the sub-SIP-NMS registers its new point of attachment and IP address with the parent-SIP-NMS. Next the sub-SIP-NMS sends a ReINVITE request with an embedded URI list through the parent SIP-NMS to the P-CSCF, which is also the SIP-FS, for re-inviting all its corresponding SIP clients. Another important observation is that, unlike in the previous case, the IP address acquiring process of the PAN does not employ MIP; thus every time it joins a new mobile network a seamless session handoff may not be guaranteed.

IV. SIMULATION RESULTS

The OPNET Modeler 14.0 platform is used for evaluating the performance of the presented architecture. A fully operational SIP-IMS model is designed and integrated to the UMTS Special Module, which is currently available under the contributed models library [14]. Necessary changes are made for SIP Proxy Servers (UASs) to operate as different CSCFs, UAC processes to communicate with modified UASs, IMS-SIP based messaging to flow between CSCFs, introduce global roaming between multiple domains, and necessary process delay controls (i.e. for messages sent between CSCFs and the HSS queries). Thus a UMTS cellular network fully capable of IMS based SIP signaling for session management and route optimization is developed. Furthermore, below the IMS architecture, a MIPv4 framework is also constructed for providing IP mobility and global reachability.

Followed by this, a heterogeneous network is designed with MIP and SIP signaling similar to the illustration of Fig. 1. Since the IMS and the MIP protocol are implemented at the core network of the UMTS cellular network, the exchange of signaling is independent to the underlying Physical and Link Layers. By taking the facts and limitations of OPNET, a fully IP based heterogeneous test bed is designed by interworking a UMTS network with a WiMAX network. Further information regarding this simulation platform is available via [10]. Following this, a group of SIP UACs that roams together are created to give the notion of a mobile network. There also exists a roaming SIP B2BUA within this group, which acts as the SIP-NMS. The SIP-NMS and the P-CSCF/SP-FS jointly handle the SIP URI list services.

When the mobile network roams from WiMAX to UMTS, the SIP-NMS residing in the group combines the source and destination addresses of all its ongoing SIP sessions into a URI list. Next, the SIP-NMS embeds this URI list into a SIP ReINVITE request and sends it to the SIP-FS of the newly attached network. When the SIP-FS receives the SIP

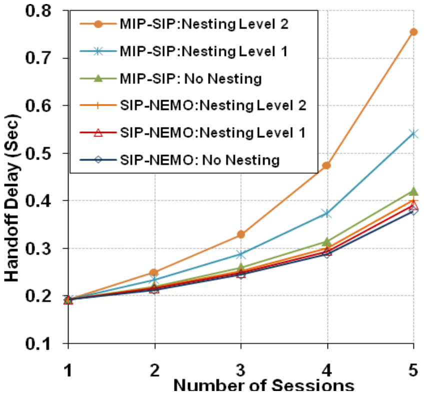

Figure 3. Handoff Delay – WiMAX-to-UMTS.

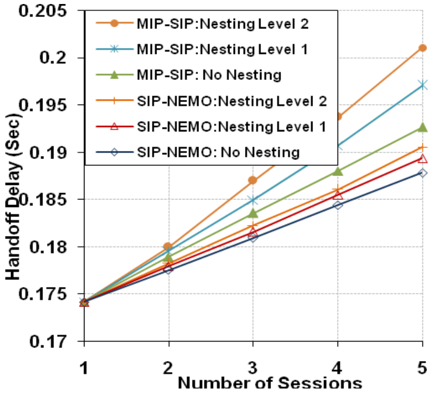

Figure 4. Handoff Delay – UMTS-to-WiMAX.

ReINVITE request with a URI list, it generates individual SIP ReINVITE requests for all the ongoing sessions that need to be handed-off to the new network (i.e., UMTS). This platform is used for simulating and evaluating the performance of SIP-NEMO assisted vertical handoff and route optimization for a network handoff, and a nested network handoff scenario. The results are compared against a non NEMO based (i.e., MIP-SIP based) method outlined in [10].

The average vertical handoff delays for SIP clients roaming from WiMAX-to-UMTS and UMTS-to-WiMAX are illustrated in Fig. 3 and Fig. 4, respectively. These graphs clearly compare the handoff delay for SIP-NEMO against a non-NEMO mechanism (known as a MIP-SIP assisted handoff mechanism). For each mechanism (i.e., SIP-NEMO and MIP-SIP) three scenarios are considered; namely, with no nesting, with one level of nesting, and with two levels of nesting. Irrespective of having SIP-NEMO support or otherwise, the average vertical handoff delay for a single session from WiMAX-to-UMTS is 192 ms and from UMTS-to-WiMAX is 174 ms. In this case, where the SIP-NMS merely works as a SIP proxy, hence the reason for SIM-NEMO and the normal handoff method to incur equal delays as the SIP URI list simply contains a single entry. Also, the reason for WiMAX-to-UMTS handoffs to indicate a relatively higher handoff and route optimization delay is due to the relatively lower bandwidth and the complicated structure of the UMTS Terrestrial Radio Access Network (UTRAN).

As the number of SIP enabled mobile nodes onboard the roaming mobile network increases (i.e., as the number of sessions increase), benefits of our proposed method become apparent. For example, as per Fig. 3, when two SIP clients are onboard the roaming mobile network, where no nesting is involved, the SIP-NEMO method reduces the handoff delay by approximately 5 ms in comparison to performing individual MIP-SIP assisted handoffs according to [10], which is actually a reduction by 2.5%. Furthermore, as the number of SIP clients onboard the mobile network increases, SIP-NEMO mechanism shows reduced handoff delays for all observed scenarios (i.e., with no nesting, with one level of nesting, and with two levels of nesting). For example, as the number of SIP clients onboard the roaming mobile network becomes 5, for a no nesting scenario the SIP-NEMO framework is capable of reducing the handoff delay close to 15 %.

Figures 3 and 4 also illustrate the behavior for a single level nested mobility scenario (e.g., for the PAN illustrated in Fig.1) and the same in the case of a double nested mobility scenario (e.g., a PAN residing in a VAN in a mobile network). As the level of nesting increases, there seem to be a clear diversion between the non-NEMO and SIP-NEMO graphs. That is, there seem to be a drastic increase in the delay for the non-NEMO graphs in comparison to the SIP-NEMO graphs. This is a direct result of the accumulated message overheads relating to MIP assisted individual route negotiations. These overheads include additional extension headers, effects of

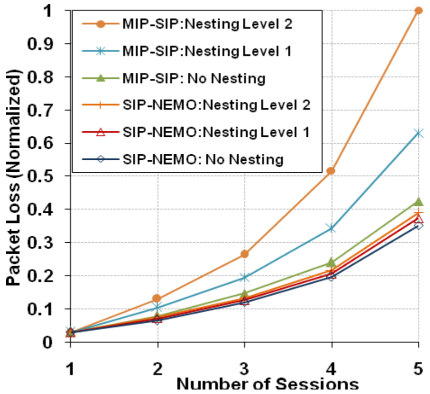

Figure 5. Transient Pkt Loss – WiMAX-to-UMTS.

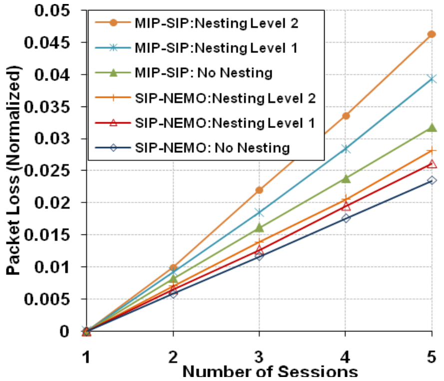

Figure 6. Transient Pkt Loss – UMTS-to-WiMAX.

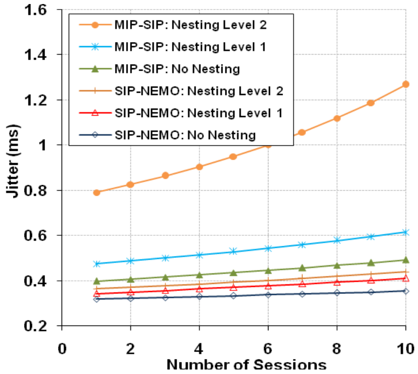

Figure 7. Jitter – WiMAX-to-UMTS.

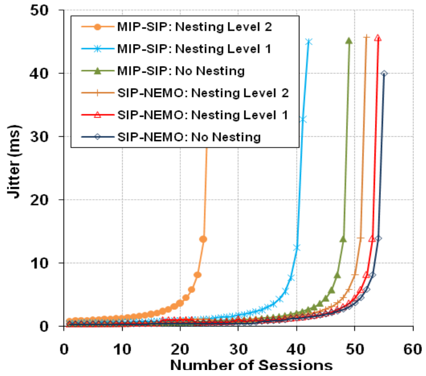

Figure 8. Jitter (Extended) – WiMAX-to-UMTS.

pinball routing, and bidirectional tunneling. As the level of nesting increases the delay caused by MIP route negotiations become more apparent due to the elevated pinball routing activities. Despite the increasing delays of MIP related handoffs and route optimizations, in all these scenarios, all SIP-NEMO scenarios show relatively low delays. Hence it can be concluded that, SIP-NEMO performs extremely well even under a nested scenario with minimal delay.

Figures 5 and 6 illustrate the normalized transient packet loss against the handed-off sessions from WiMAX-to-UMTS and UMTS-to-WiMAX networks respectively (Note: This is in the case of a break-before-make handoff scenario taking place). A relatively higher transient packet loss is observed from the WiMAX-to-UMTS in Fig. 5 in comparison to the UMTS-to-WiMAX in Fig. 6. As the transient packet loss during a vertical handoff is directly proportional to the vertical handoff delay, SIP-NEMO assisted session handoffs incur relatively lower packet losses in contrast to the comparison graphs obtained from [7].

Lastly, Figs. 7 and 8 illustrate the jitter comparison for WiMAX-to-UMTS network handoffs for MIP-SIP and SIP-NEMO mechanisms. In this case, the jitter plot is obtained by calculating the variation of the end-to-end delay over UMTS for sessions that are being handed-off. According these graphs, the jitter rates are within acceptable limits for VoIP applications. Furthermore, these jitter graphs tend to indicate rather exponential curves as per Fig. 8 beyond a certain number of sessions. However, still the SIP-NEMO related jitter graphs show a relatively stable behavior up to about 50 parallel sessions in contrast to the non NEMO approach, which is a good indication of its limitations.

V. CONCLUSIONS

This paper proposed SIP-NEMO based group and nested group mobility support for PANs travelling in a VAN between multiple heterogeneous networks. The proposed solution introduced SIP-NEMO into the IMS, which was also the coupling mediator of the underlying NGMN architecture. Further, the P-CSCF of the IMS functioned as the SIP-FS of the SIP-NMS, thus easily enabling group mobility and route optimization. Since both the P-CSCF and the SIP-FS are SIP B2BUAs, this was achieved with minimal changes to the existing 3GPP and 3GPP2 standards. The introduction of SIP-NEMO for facilitating group and nested group based session mobility support and route optimization introduced a significant reduction in signaling overhead, hence substantially increased the end user QoS. Results and analysis illustrated that by integrating NEMO support to an NGMN reduced handoff latency, transient packet loss, jitter for both end users and service providers.

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