On the Impacts of Distributed and Dynamic Mobility Management Strategy: A Simulation Study

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***Abstract*—The explosive increase in Internet traffic definitely requires operators to turn their eyes to a flat-based mobile architecture, providing scalable and reliable mobility solutions for future evolved mobile networks. Distributed and Dynamic Mobility Management (DMM) is one of the main enablers to implement the flat-based mobile architecture, placing anchor functions at the edges and providing dynamic mobility activation. In this paper, we perform a simulation study to assess the impact of the DMM strategy, focused on the data plane, in mobile networks. The main objective of this paper is to identify how much DMM can be effective in reducing network stresses imposed on the mobile backhaul and core networks, compared to Proxy Mobile IPv6 (PMIPv6) having excellent handover performance among centralized mobility protocols. Simulation results demonstrate that DMM is effective to improve packet delivery efficiency and to mitigate the network stresses due to IP mobility support by distributing anchoring burdens and eliminating the need of packet anchoring.**

Keywords*—Mobile Network, Proxy Mobile IPv6, PMIPv6, Distributed Mobility Management, DMM, Distributed Mobile Network.

I. Introduction

Flat-based IP mobility management is one of the critical enablers for future mobile networks. It resorts typically to the distributed mobility management (DMM) as opposed to the centralized mobility management (CMM) where the mapping information between the persistent node identifier and the changing IP address of a mobile node (MN) is kept at a single mobility anchor [1]. Mobile IPv6 (MIPv6) — a representative IP mobility protocol based on the CMM approach — introduced a way of providing IP session continuity for MNs [2]. However, there have been many issues with regard to poor performance and scalability in the protocol operation. Since then, the studies for the protocol enhancements have focused on improving user handoff performance. Hierarchical Mobile IPv6 (HMIPv6) tried to improve scalability of Mobile IP by deploying Mobility Anchor Points (MAPs) to manage a number of access routers (ARs) in HMIPv6 domain, thus reducing unnecessary binding update signaling messages from a MN to a home agent (HA) [3]. Proxy Mobile IPv6 (PMIPv6) has been standardized in IETF, providing network-based mobility management without any protocol involvement in the host side, i.e. movement detection and binding update are initiated and performed by PMIPv6 agents. This significantly contributes to the reduction of handoff latency [4]. However, such protocol enhancement strategies based on the CMM approach have limitations in addressing single points of failure and introduce severe workload burden on anchor points, leading to the increase of unreliability in IP mobility support [5]. These problems will be even more severe in future Internet environments where mobile Internet traffic consumption tends to explosively increase, monthly global data traffic is predicted to surpass 10 exabytes in 2016, and video is expected to be the dominant traffic type among the whole [6]. These concerns made mobile operators gain interest in DMM as one of the flat-based IP mobility approaches and led to the creation of Distributed Mobility Management (DMM) WG in IETF[1]. There are no standardized solutions presented yet. However, the conceptual operation in data plane to be provided by DMM is addressed, with two complementary aspects of mobility management: the distribution of mobility anchors and the dynamic activation of IP mobility support [1].

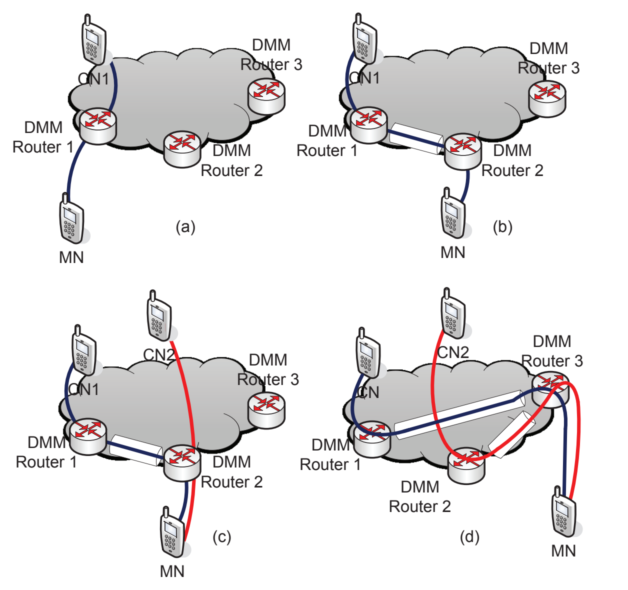

Fig. 1. Two main aspects to realize a flat-based IP mobile architecture: distribution of mobility anchors and dynamic activation of mobility protocol support

[1] IETF DMM WG status, http://wiki.tools.ietf.org/wg/dmm

Fig. 1 shows packet routing operations for different IP flows initiated at different DMM routers (DMRs)[2] as a MN moves to DMR3 from DMR1, regardless of the design of the control plane. Simple descriptions of the sub-figures in Fig. 1 are as follows; *a*) the MN performs IP communication with CN1 by regular IP routing, with no mobility activation; *b*) the MN is currently attached to DMR2; when DMR1 receives the packets destined to MN by CN1, the packets are forwarded to the MN through the established tunnel between DMR1 and DMR2; *c*) a new session is initiated by CN2, and IP packets belonging to the new session are exchanged between the MN and CN2 by regular IP routing, while CN1's session is anchored at DMR1 and the packets are forwarded through the established tunnel between DMR1 and DMR3; *d*) when the MN is attached to DMR3, each of existing sessions initiated by CN1 and CN2 is anchored at DMR1 and DMR2, and the packets destined to MN, sent by CN1 and CN2, are intercepted at each anchor and forwarded to DMR3, respectively.

Such a packet routing scheme has already been applied in several DMM protocol proposals with different designs of control plane. In [7], it proposed a network-based mobility approach taking benefits of MN-unawareness into DMM, with the classification of fully/partially-distributed DMM. The concept of home/visited mobility anchors was applied in DMM protocol design [8]. P. Bertin et al. proposed a flat-oriented mobile architecture named dynamic mobility anchoring (DMA), which was evaluated against MIPv6 in terms of handover latency [9], TCP segment delay and end-to-end packet delay [10]. Recently, it was evaluated against PMIPv6 in terms of packet delivery cost, signaling cost, and processing/tunneling costs in [11]. In [12], MIPv6-based DMM, PMIPv6-based DMM, and SIP were evaluated in terms of handover latency and packet loss. Contemplating the previously proposed DMM studies from performance metric perspective, most efforts have been dedicated to show user-centric performance improvement with the relevant metrics as listed above. These metrics may be necessary to see the overall performances of proposed mobility protocols based on the DMM strategy but are not sufficient to definitely address DMM-specific characteristics, which can be described by such as distributed workload throughout the network, released traffic intensity, and reduced link stress on mobile networks, compared to the CMM.

In this paper, we conduct a simulation study to assess the performance of DMM strategy, especially focused on data plane in mobile backhaul and core networks. The main objective of this performance study to identify how much network stresses can be released by DMM. PMIPv6 is targeted as one of representative IP mobility protocols following CMM approach and providing excellent handover performance, adopted one in various standardization bodies [13][14]. The signaling impact is highly associated with the design of control plane, such as how and where the mapping information is obtained from and which signaling protocol is used. Since it has not been standardized yet, it is out of scope in this paper. Then, signaling impacts are not investigated but only data plane are targeted.

The remainder of this paper is organized as follows. In Section II, we assess the performance of DMM and PMIPv6 on a developed simulator based on a mathematical analysis. Simulation results are provided in Section III. We conclude this paper in Section IV.

[2]Currently, there is no standard name pointing out a DMM-enabled router so that we simply call this a DMM router (DMR) throughout this paper.

II. Simulation

In this section, we describe a simulator using Matlab, running on a given topology and measuring several performance values based on mathematically analyzed equations. The evaluated performance metrics are as follows.

- Packet delivery cost: this represents how many routing hops have been travelled to deliver packets from a CN to the MN.
- Anchored/non-anchored packet ratio: this represents how many packets have been anchored or not anchored (non-anchored) among all the packets sent by corresponding nodes (CNs) to the MN, thus indirectly indicating the effect of dynamic mobility anchoring to reduce the network costs.
- Traffic distribution ratio: this represents how widely packets have been routed over the network, showing how DMM contributes to the distribution of packet routing compared to PMIPv6.

A. Simulation Topology

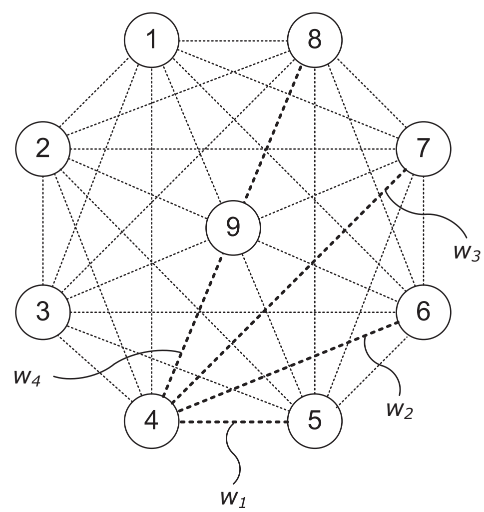

Fig. 2. A network topology for simulations

Fig. 2 shows a network topology employed in our simulation. The nodes shown in Fig. 2 represent routers, which take different roles for DMM and PMIPv6, respectively. We call the nodes as routers to distinguish from mobile nodes or correspondent nodes. It is critical to have a topology to investigate network stresses imposed on mobile core networks. The given topology reflects highly-dense mobile environments, where users are crowded with highly mobile condition and are surrounded by many buildings consisting of a large number of micro-cells, thus where DMM will be highly required. Besides, the given topology is advantageous to reflect a longer routing impact that should be critically taken into account DMM performance evaluation. (For more details, refer the last paragraph in current sub-section to see how a longer routing impact is applied in the given topology.)

In PMIPv6, MAGs are placed at the edges (from 1 to 8) and the LMA (node 9) is placed in the center of the topology, while DMM takes all edge routers as anchors but the router 9 is used for just packet routing when a packet is needed to go through it, not excluding it for fair comparison in the both cases. CNs are located at arbitrary edge routers. The dotted lines show available routing paths to send packets between the routers. Packets are transmitted with the shortest routing path between the edge routers of the MN and CNs. Packet delivery examples for PMIPv6 and DMM are as follows. A CN and a MN are attached to the routers 1 and 4, respectively, and the MN moves to routers 5 and then 6. In PMIPv6, the packet sent by the CN goes through routers $1 \rightarrow 9 \rightarrow 4$, so when the MN moves to router 5, the routing path is changed like $1 \rightarrow 9 \rightarrow 5$. In DMM, the packet sent by the CN is directly routed from routers 1 to 4 ($1 \rightarrow 4$) by regular IP routing. When the MN moves to router 5, the packet goes through routers $1 \rightarrow 4 \rightarrow 5$. Following the described packet routing operations on the topology, we compute various costs imposed on mobile backhaul, such as *i*) how many routing hops are required to deliver packets from a CN to the MN; *ii*) how many packets have been anchored or not anchored (non-anchored); *iii*) how widely packets have been routed on the network.

In the simulator, the packet delivery cost is computed based on a mathematical analysis. Since the anchor function in DMM is located at edge routers, the routing distance differentiated between the anchor router and current serving router changed as the MN moves from its anchor router should be essentially taken into account. However, it is not easy to obtain the differentiated routing distances with regularity. In [11], the routing distance between any pair of edge routers was assumed to be same with a fixed value. In [15], the number of routing hops was also assumed to be a fixed value on average but different weight factors were applied for each hop in the core and access networks. When we follow such a scheme defining routing distance, the total routing hop distances will be accumulated by repeatedly adding fixed routing hop values as many times as the MN has travelled. However, such a way does not reflect optimized routing effect between the anchor router and current serving router.

In our performance evaluation, we devise a way of defining and imposing a weight factor on routing paths having different geometric values. So, all the routing distances are differentiated depending on the geometric distance between any pair of edge routers, and between an edge and the core routers. Hence, we define a routing hop distance (*d*) between any arbitrary two routers is proportional to the computed weight factor (*w*) and a unit routing hop is (*r*). Therefore, d_{X-Y} can be expressed as $w{\cdot}r$, as a routing hop distance between routers *X* and *Y*. The geometric values between routers are calculated using Pythagorean Theorem. In the simulation topology shown in Fig. 2, there are four kinds of weight factors, i.e. w_1, w_2, w_3, and w_4 on different geometric distances. In case the weight factor for a route where the difference of router index numbers is 1, e.g. between the routers 4 and 5, w_1 is assumed to be 1. When the difference of router index numbers is 2, 3, and 4, i.e. w_2, w_3, and w_4, each weight factor can be obtained as $\sqrt{2+\sqrt{2}}$, $1+\sqrt{2}$, and $\sqrt{4+2\sqrt{2}}$, respectively, and the weight factor between router 9 and the edge routers can be obtained as $0.5{\cdot}w_4$.

B. User Mobility and Traffic Models

We assume that a MN moves around every MAG/DMR sequentially, i.e. from routers 1 to 8, staying at each MAG/DMR during a residence time that follows exponential distribution with mean $1/\mu_R$. There are *m* static CNs, whose locations are randomly chosen among 8 edge routers when each session is generated by following uniform distribution. Each CN is assumed to generate one session so the total number of active sessions at any given time is under *m*. And each session lasts during its session duration time that follows exponential distribution with mean $1/\mu_D$. The anchor router for a newly established session is determined as the router to which the MN is attached when the session is created between the MN and CN in DMM, whereas the anchor (LMA) in PMIPv6 is always the router 9 on the topology. The packet arrival time in an established session follows an exponential distribution with rate λ_S, which is assumed to be identically applied to mobility and non-mobility sessions, i.e. whatever they are anchored or not. Let T_S and T_R be the random variables for inter-packet arrival time and MAG/DMR residence time, with the means of $1/\lambda_S$ and $1/\mu_R$, respectively. We assume that there are no packet loss while the MN moves, providing an easy way to distinguish simply routed or anchored packets.

C. Packet Delivery Cost

Packet delivery cost (C_{PD}) is defined as the sum of regular IP packet routing cost (C_{PR}) from CN's serving router to the MN's anchor for the session associated with a CN and packet forwarding cost (C_{PF}) from the MN's anchor for the session to the MN's current serving router as defined in (1).

$$C_{PD} = C_{PR} + C_{PF} \tag{1}$$

C_{PD} does not take into the cost in wireless account, i.e. packet delivery cost between MN/CN and its serving router because they are the same in both mobility approaches. In DMM, a DMR is distinguished into S-DMR and A-DMR, where S-DMR and A-DMR denote serving and anchor DMRs, respectively. In order to compute C_{PD}, we use Little's law [17]. The number of packets during T_R can be approximated by $\lambda_S{\cdot}T_R$ [16]. Therefore, the C_{PR} is obtained by

$$C_{PR} = \lambda_S \cdot T_R \cdot C_{X-Y} \tag{2}$$

where *X* is a MAG/S-DMR to which *i*-th CN (CN_i) belongs and *Y* denotes MN's LMA/A-DMR where the packets sent from CN_i are anchored. C_{X-Y} is given by $d_{X-Y}{\cdot}L_P$ or $d_{X-Y}{\cdot}(L_P + L_T)$ depending on use of packet tunneling, where L_P is average packet length and L_T is tunnel header length (40 bytes). C_{PF} is obtained by Little's law used in C_{PR} calculation, taking into account the number of packets transmitted from MN's LMA/A-DMR to MAG/S-DMR. Therefore, C_{PF} is given by

$$C_{PF} = \lambda_S \cdot T_R \cdot C_{Y-Z} \tag{3}$$

where *Z* is the MAG/S-DMR at which the MN is staying. C_{X-Y} and C_{Y-Z} for PMIPv6 and DMM are obtained as follows.

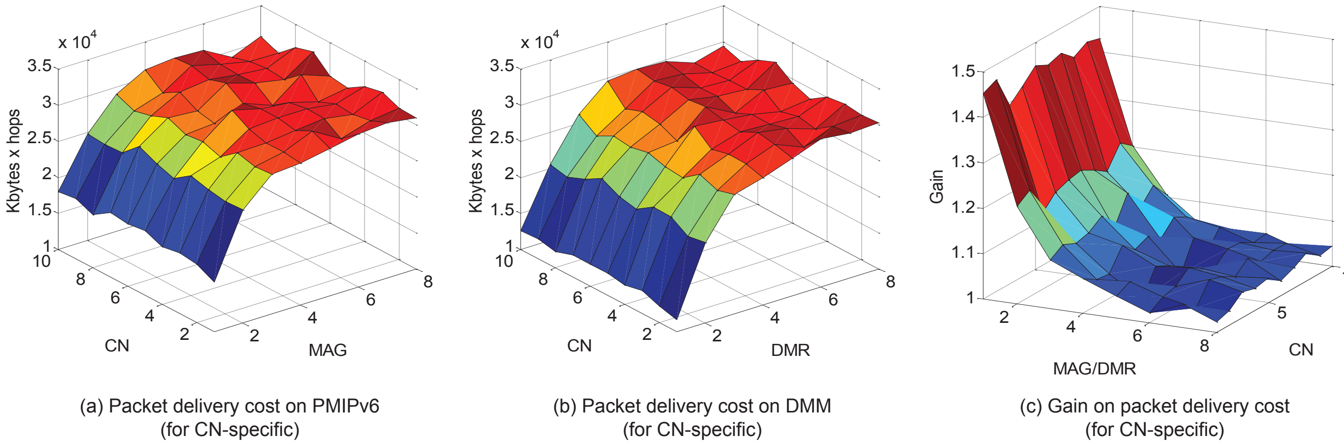

Fig. 3. Packet delivery cost comparison in PMIPv6 and DMM

$$C_{X-Y}^{PMIPv6} = d_{X-Y} \cdot (L_P + L_T) \tag{4}$$

$$C_{X-Y}^{DMM} = d_{X-Y} \cdot L_P \tag{5}$$

$$C_{Y-Z}^{PMIPv6} = C_{Y-Z}^{DMM} = d_{Y-Z} \cdot (L_P + L_T) \tag{6}$$

In PMIPv6, packet tunneling is used in C_{PR} and C_{PF} as shown in (4) and (6) however L_T in both equations will be 0 due to MAG local routing, which is enabled when the MN and a CN is under same MAG. In DMM, there is no packet tunneling in C_{PR}, as shown in (5), however L_T in (4) and (6) will be 0 when the MN stays at the A-DMR.

D. Packet Anchoring/Non-Anchoring Ratios

We compute the number of packets that have been anchored at each anchor router, evaluating anchoring stress on each anchor router. To show the effect of dynamic mobility anchoring, the ratios of anchored (ACR) and non-anchored packets (NACR) over total number of packets processed in the routers are used as (7) and (8), where the non-anchored packet is defined that it should have been anchored but they are routed by regular IP routing on *j*-th DMR or MAG, when we take into consideration anchored packet routing has been one of main factors spending more resources to process and more time to deliver the packets than non-anchored (direct) packet routing. The sum of all anchored and non-anchored packet ratiosthe defined ACR and *NACR* on all the nodes is obviously 1.

$$ACR_{scheme}^{j} = \frac{\text{No. of anchored packets on the node } j}{\text{No. of total packets processed on node } j} \tag{7}$$

$$NACR_{scheme}^{j} = \frac{\text{No. of non-anchored packets on node } j}{\text{No. of total packets processed on node } j} \tag{8}$$

E. Traffic Distribution Ratio

Traffic distribution ratio shows how widely packets have been routed by counting the number of packets travelled on routing the paths established between the any two routers, as given by (9), where k and l denote any two arbitrary router indexes in the topology. The number of packets routed between routers k and l will be counted once, regardless of the routing direction, i.e. from k to l or l from to k. The sum of all routed packet ratio will be 1.

$$T_{scheme}^{k,l} = \frac{\text{No. of packets travelled on the path btw. } k \text{ and } l}{\text{No. of total packets in the network}} \tag{9}$$

III. Simulation Results

The following parameter values from the literature [16] are used as default in the simulation; packet size (L_P) is 1500 bytes, the total number of CNs (*m*) is 10 and λ_S is set to 200 (pkts/sec). The packet delivery cost is expressed as the product of message length and routing hop distance, as defined in (2) and (3), and then the unit is $Kbytes \times hops$ [18]. Average residence time is 600s and average session duration time is 360s. The results are obtained on average from 10000 times simulations.

A. Packet Delivery Cost

Fig. 3 shows the packet delivery cost in PMIPv6 and DMM, where X-axis and Y-axis denote the indexes of the CN and MAG/DMR, respectively, as the MN moves from the MAG/DMR 1 to 8. DMM shows lower packet delivery cost than PMIPv6 as shown in Figs. 3 (a) and (b), especially in the initial stage where the MN is under MAG/DMR 1 to 3. This is because the most of CN sessions generated at the moment are not anchored or the rest of the sessions are routed using relatively shorter routing hop distance between neighboring DMRs in DMM than PMIPv6. In PMIPv6, all the packets have been routed through the LMA all the time except the case of MAG local routing. So, the routing hop distances for

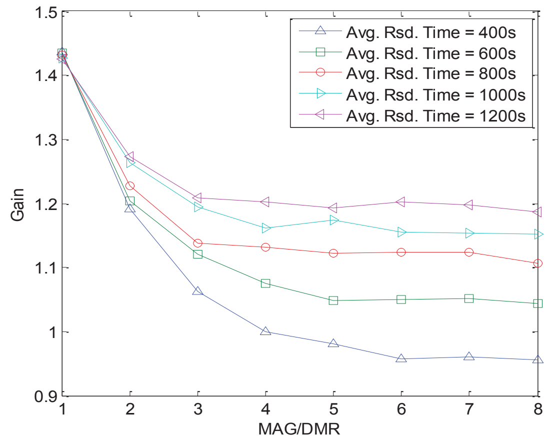

Fig. 4. Packet delivery cost gain according to average residence time

the routed packets in PMIPv6 are almost constant with the relatively long routing distances.

As the MN keeps moving towards DMR 8, the probability that CNs' sessions will be anchored increase, the packet delivery cost gradually increases. When the MN passes through DMR 6, this increase reveals a smooth slope in both cases because the mobility sessions of most CNs are terminated. Fig. 3 (c) aims to show the cost gain obtained from dividing the PD cost in PMIPv6 by the PD cost in DMM. At the initial time, DMM is highly gained from regular IP routing thanks to the dynamic mobility characteristic and the short forwarding distance between neighboring routers. Fig. 4 shows the packet delivery cost gain, where the average session duration time is 360s as the average residence time is increased from 400s to 1200s. As the residence time is bigger, the handoff count decreases and the anchored traffic traveling long routing distance also decreases.

B. Packet Anchoring/Non-Anchoring Ratios

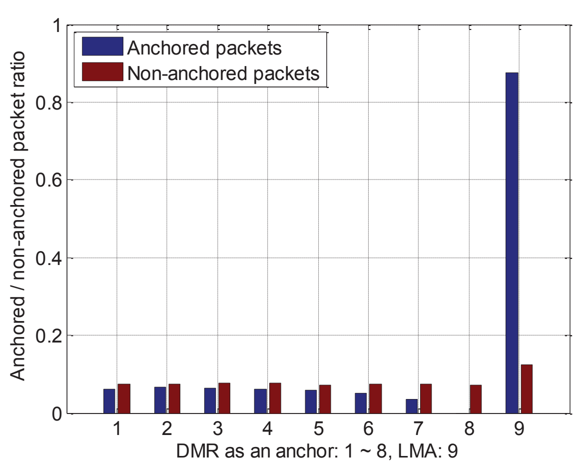

Fig. 5. Anchored and non-anchored packet ratio

In Fig. 5, the numbers from 1 to 8 denote the indexes of DMRs in DMM while the number 9 denotes LMA in PMIPv6. The non-anchored packets are meant as the packets should have been anchored but they are routed due to MAG local routing in PMIPv6. The number of non-anchored packets — resulted from MAG local routing in PMIPv6 — are aggregated and displayed on the router 9 position to provide better visual comparison of non-anchored packet ratio by seeing all routers as an anchor perspective. In DMM, the non-anchored packets are counted when the MN stays at the anchor router of each session the MN is associated with. Anchored packet ratio ranges from 0.035 to 0.066 in all DMRs, while the ratio is 0.8768 at the single LMA in the PMIPv6. Considering the number of anchor routers is 8 in DMM, we can simply imagine anchored packet cost ratio on single DMR would be 0.1096 on average, as dividing 0.8768 by 8. However, the anchored packet ratio on each DMR in DMM shows 13 to 25 times lower than that on LMA in PMIPv6. This improvement of less packet anchoring is the result from the larger number of non-anchored packets relatively than that of anchored packets in DMRs. This reveals that DMM has great effect of reducing packet anchoring thanks to dynamic mobility anchoring. Additionally, it shows anchored packet ratio is 7 times the non-anchored packet cost ratio in PMIPv6, even though MAG local routing is enabled. It indirectly demonstrates PMIPv6 MAG local routing on the centralized mobility approach is not as scalable in the reduction of anchoring cost as DMM.

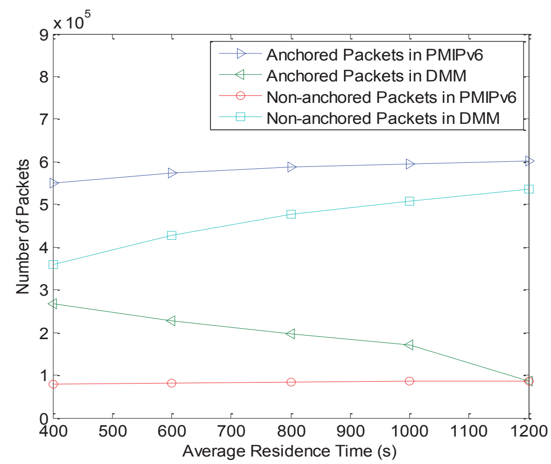

Fig. 6. Anchored/non-anchored packets in PMIPv6 and DMM

Fig. 6 shows the effect of the average residence time on anchored and non-anchored packets in PMIPv6 and DMM, where an average session duration time is fixed with 360s. Increasing residence time means the MN is moving with a lower mobility rate. In PMIPv6, the number of anchored packets and non-anchored packets are not much affected over the given range of average residence time, while, in DMM, the number of anchored packets gradually decreases and the number of the non-anchored packets increases. This is because MNs spend more time for staying in the routers where the routing hop distances are short from the anchors as the average residence time is higher, therefore the number of handoffs becomes lower. Eventually, a long routing impact highly decreases. On the other hand, it means that the low average residence time, i.e. high mobility rate can decrease the efficiency of DMM performance.

C. Traffic Distribution Ratio

Fig. 7 shows traffic distribution ratio in PMIPv6 and DMM, revealing that how widely the data traffic has been spread over all the available routing paths on the given topology. The traffic distribution ratio ranges from 0.021 to 0.056 in DMM, while the ratio ranges from 0.1003 to 0.1326 in PMIPv6. These values show that the same amounts of packets in PMIPv6 have travelled through narrow range of routing paths than DMM because a few routing paths between MAGs and LMA are used in PMIPv6, while more diverse and optimized routing paths are used to deliver packets in DMM.

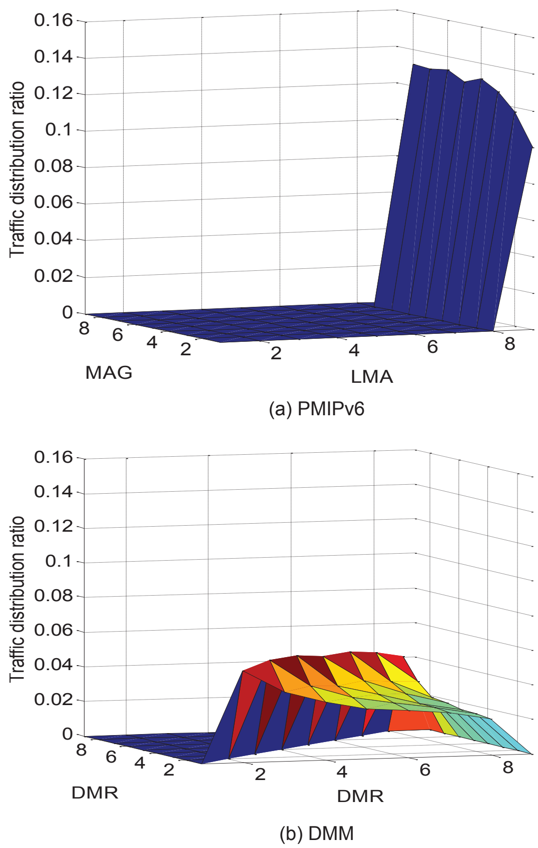

Fig. 7. Traffic Distribution Ratio over all the routing paths

From the obtained results, we identified that DMM approach contributes to the distribution of overall network traffic as well as the reduction of network stress due to packet anchoring. And it can be foreseen that DMM would indirectly contribute to link traffic congestion avoidance and improved data transmission speed.

IV. Conclusion

In this paper, we investigated the performance impacts of distributed deployment of mobility anchoring and dynamic mobility activation and compared them with PMIPv6 through extensive simulations. Simulation results have been presented in terms of packet delivery cost, anchored/non-anchored packet ratio, and traffic distribution ratio. Besides, the impact of average residence time has also been assessed. Simulation results demonstrate that DMM is effective to improve packet delivery efficiency and to mitigate the network stresses due to IP mobility support by distributing anchoring burdens and reducing the need of packet anchoring.

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