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End-to-End Delay Analysis of a Dynamic Mobile Data Traffic Offload Scheme using Small-cells in HetNets

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ABSTRACT

Recently, the traffic volume of mobile communications increases rapidly and the small-cell is one of the solutions using two offload schemes, i.e., local IP access (LIPA) and selected IP traffic offload (SIPTO), to reduce the end-to-end delay and amount of mobile data traffic in the core network (CN). However, 3GPP describes the concept of LIPA and SIPTO and there is no decision algorithm to decide the path from source nodes (SNs) to destination nodes (DNs). Therefore, this paper proposes a dynamic mobile data traffic offload scheme using small-cells to decide the path based on the SN and DN, i.e., macro user equipment, small-cell user equipment (SUE), and multimedia server, and type of the mobile data traffic for the real-time and non-real-time. Through analytical models, it is shown that the proposed offload scheme outperforms the conventional small-cell network in terms of the delay of end-to-end mobile data communications and probability of the mobile data traffic in the CN for the heterogeneous networks.

☞ keyword : heterogeneous networks, small-cell networks, dynamic, LIPA, SIPTO, traffic offload, delay.

1. Introduction

The rapid growth of mobile data traffic from mobile devices, e.g., smart phones, machine-to-machine, and so on, has been widely recognized and most of the traffic volume occurs in indoor environments [1]. Based on the recent report, the amount of global mobile data traffic approximately increases seven times from 12 exabytes (EB) to 77 EB in 2017 and 2022, respectively [2]. A promising solution to improve the system capacity of access networks with frequency reuse is small-cells in heterogeneous networks (HetNets) because they increase both the coverage and system capacity with low energy consumption [3]-[4]. However, even though small-cell networks (SCNs) have diverse advantages, they can not reduce the amount of mobile data traffic in the core network (CN) since small-cell access points (SAPs) always send their mobile data traffic from small-cell user equipments (SUEs) to the CN through the Internet. In order to reduce the amount of mobile data traffic in the CN, the 3GPP has enhanced two mobile data traffic offload schemes named local IP access (LIPA) and selected IP traffic offload (SIPTO) to offload the mobile data traffic to the Internet for SCNs [5]-[6]. Thus, in the world, major mobile network operators (MNOs) have been showing a great deal of attention to use small-cells with LIPA and SIPTO for the next generation mobile networks, i.e., LTE-Advanced and 5G [7]-[10]. However, most of research work only introduce the concept of LIPA and SIPTO and thus a path decision algorithm with analytical research requires in this area.

In this paper, we propose a dynamic mobile data traffic offload scheme to reduce the delay of end-to-end mobile data communications and amount of mobile data traffic in the CN using SAPs in HetNets. In the proposed scheme, the SAP first decides the path from source nodes (SNs) to destination nodes (DNs) based on the device of the DNs, i.e., macro user equipment (MUE), SUE, and multimedia server (MS), and type of the mobile data traffic for the real-time (RT) and non-real-time (NRT). And then, the SAP offloads the mobile data traffic between SNs and DNs using LIPA and SIPTO in various scenarios. Through analytical models, it is shown that the proposed scheme outperforms the conventional SCN in terms of the delay of end-to-end mobile data communications

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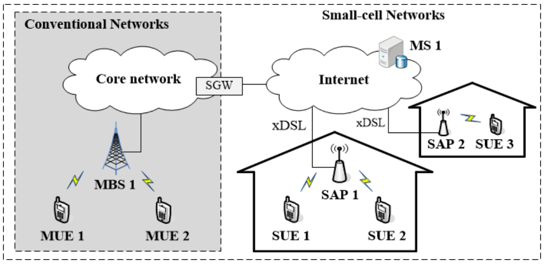


(Figure 1) The structure of conventional mobile networks and small-cell networks.

(Table 1) Seven scenarios with different SNs and DNs for mobile data communications in the SCN.

Scenarios	Source nodes(SNs)	Destination nodes(DNs)
S1	MUE 1	MUE 2
S2		MS 1
S3		SUE 2
S4	SUE 1	MS 1
S5		SUE 2 (same SAP)
S6		SUE 3 (different SAPs)
S7		MUE 2

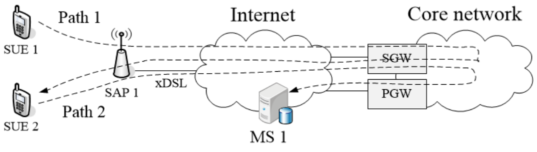
for SUEs and probability of the mobile data traffic in the CN for the HetNet.

The remainder of this paper is organized as follows. Section 2 introduces various scenarios with different SNs and DNs for mobile data communications using the LIPA and SIPTO in the SCN and Section 3 explains the proposed dynamic mobile data traffic offload scheme using SAPs. Then, Section 4 evaluates the system performance and section 5 concludes this paper with future research direction.

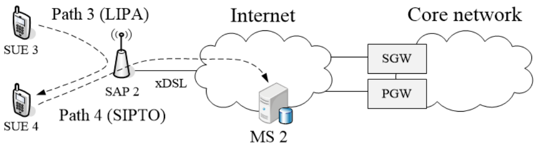
2. Related Work

2.1 SCNs and seven scenarios

Fig. 1 shows the structure of conventional mobile networks and SCNs. The conventional mobile network consists of the CN, macro base stations (MBSs), and MUEs while the SCN has a couple of additional units, i.e., small-cell gateways (SGWs), SAPs, and SUEs, to the conventional mobile network. When users install SAPs at home or in the office, the SAPs are connected to the SGW. Then, the SUEs make connections with their serving SAPs that give the strongest signal strength instead of the MBS, i.e., the SUEs communicate with the CN through their serving SAPs, Internet, and SGWs. Therefore, small-cells can reduce the overhead of MBSs but the CN still has the overhead of the mobile data traffic since the SAPs always transmit the mobile data traffic from SUEs to the CN.



(a) SCNs without LIPA and SIPTO



(b) SCNs with LIPA and SIPTO

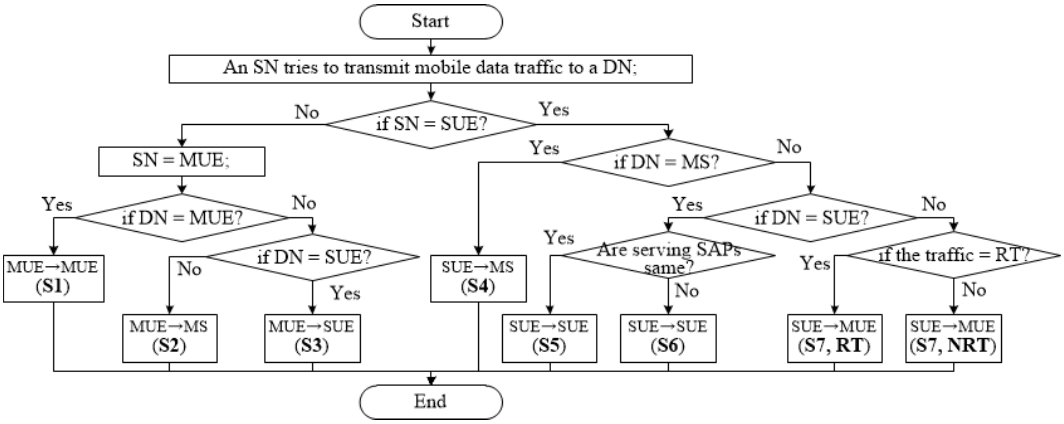
(Figure 2) Different paths of the mobile data traffic in SCNs without/with LIPA and SIPTO.

Table 1 describes seven scenarios with different SNs and DNs for mobile data communications of the SCN as shown in Fig. 1. In Table 1, the SN is either MUE 1 or SUE 1 while the DN is different in each scenario, i.e., MUE 2, SUE 2, MS 1, and SUE 3. Especially, SUE 1 and 2 are connected to the same SAP in S5 but SUE 1 and 3 are connected to different SAPs in S6.

2.2 Traffic offload with LIPA and SIPTO

The mobile data traffic offload has currently become an essential part for MNOs because the amount of the mobile data traffic increases rapidly [3]-[4]. The standard of LIPA is to offload internal mobile data traffic from SUEs to network devices in the same residential/enterprise IP network using SAPs. On the other hand, the standard of SIPTO is to selectively offload the mobile data traffic from SUEs to MSs on the Internet, i.e., the SAPs directly communicate with the MSs through the Internet.

Fig. 2 shows examples of different paths for the mobile



(Figure 3) The flowchart of the proposed dynamic traffic offload scheme for HetNets.

data traffic from SUEs to MSs and SUEs without/with LIPA and SIPTO in SCNs [5]-[9]. Fig. 2-(a) describes conventional SCNs, i.e., SCNs without LIPA and SIPTO. Thus, SUE 1 communicates with SUE 2 through SAP 1, Internet, CN, Internet, and SAP 1, i.e., path 1, while SUE 2 communicates with MS 1 through SAP 1, Internet, CN (SGW, CN, PGW), and Internet, i.e., path 2. In other words, SAP 1 always transmits the mobile data traffic from SUE 1 and 2 to the CN and then the CN again transmits it to SAP 2 and MS 1 through SAP 1 and Internet, respectively. On the other hand, Fig. 2-(b) describes SCNs with offloading technologies, i.e., LIPA and SIPTO. Thus, SAP 2 offloads the mobile data traffic from SUE 3 to SUE 4 using LIPA, i.e., path 3, and from SUE 4 to MS 2 using SIPTO, i.e., path 4. It means that the mobile data traffic from SUE 3 and 4 is not sent to the CN and thus the amount of mobile data traffic in the CN can be reduced.

3. Proposed dynamic Offload Scheme and Analytical Models

In this section, we propose a dynamic mobile data traffic offload scheme with LIPA and SIPTO and introduce analytical models for the scenarios as shown in Table 1.

3.1 Proposed dynamic mobile data traffic offload scheme with LIPA and SIPTO

Based on the seven scenarios in Table 1, we propose a dynamic mobile data traffic offload scheme with LIPA and SIPTO for SCNs. The proposed scheme first checks the SNs and DNs and then decides the path of end-to-end mobile data communications for both RT and NRT traffic.

Fig. 3 shows the flowchart of the path decision algorithm of the proposed dynamic traffic offload scheme for HetNets. Further, Table 2 describes the path of each scenario for three different networks, i.e., conventional mobile networks, SCNs, and SCNs with the proposed scheme, using network devices. In S1 and S2, the paths for RT and NRT traffic are the same for the three networks. In the scenarios from S3 to S7, the conventional mobile network has no paths since it does not use SUEs as network devices while the SCN and SCN with the proposed scheme have the same path for RT and NRT traffic except the SCN with the proposed scheme for RT traffic in S7 because the proposed scheme changes the serving node of SUEs from SAPs to the MBS to reduce the delay of end-to-end mobile data communications. Further, in S3, the SCN and SCN with the proposed scheme have the same path. On the other hand, in the scenarios from S4 to S6, the SCN with the proposed scheme offloads the mobile data traffic using LIPA and SIPTO and thus it has different paths from those of the SCN. In S4, in the SCN, the SUE communicates with the MS through the serving SAP, Internet, CN, and Internet while in the SCN with the proposed scheme, the SUE communicates with the MS through the serving SAP and Internet using SIPTO to offload the mobile data traffic. In S5 and S6, SUEs communicate

(Table 2) The path of end-to-end mobile data communications for three different networks.

Scenarios	Traffic type	Conv.	SCN	SCN with the proposed scheme
S1	RT, NRT	MBS↔-CN↔MBS		
S2		MBS↔CN↔Internet		
S3		-	MBS↔CN↔Internet↔SAP	
S4		-	SAP↔Internet↔CN↔Internet	**SAP↔Internet (SIPTO)**
S5		-	SAP↔Internet↔CN↔Internet↔SAP	**SAP (LIPA)**
S6		-	SAP↔Internet↔CN↔Internet↔SAP	**SAP↔Internet↔SAP (SIPTO)**
S7	**RT**	-	SAP↔Internet↔CN↔MBS	**MBS↔CN↔MBS (change the serving node)**
	NRT			SAP↔Internet↔CN↔MBS

with each other but the difference is that the serving SAP is the same in S5 while it is different in S6. Thus, in the SCN, the SUEs communicate with each other through the serving SAP, Internet, CN, Internet, and serving SAP in S5 and S6, while in the SCN with the proposed scheme, they only communicate with each other through their serving SAP using LIPA and through the serving SAP, Internet, and serving SAP using SIPTO in S5 and S6, respectively.

For the last, in S7, in the SCN, the SUE communicates with the MUE and they use a path through the serving SAP, Internet, CN, and serving MBS for both RT and NRT traffic. On the other hand, in the SCN with the proposed scheme, they use different paths for RT and NRT traffic. That is, the SUE communicates with the MUE through the same path of the SCN for NRT traffic. However, the SUE first changes the connection from the serving SAP to the MBS to become a MUE and then the new MUE that was an SUE communicates with the MUE that is a DN through the serving MBS of the new MUE, CN, and serving MBS of the MUE (DN) for RT traffic (this path is the same as the path of S1) since the new path has lower delay than the previous path.

3.2 Delay from SNs to DNs

In order to analyze the delay of end-to-end mobile data communications, we introduce analytical models for three different networks, i.e., conventional mobile networks, SCNs, and SCNs with the proposed scheme. In the conventional mobile network, there are only two scenarios as shown in Table 2, i.e., S1 and S2. Let $D^{S1}_{Conv.}$ and $D^{S2}_{Conv.}$ denote the delay of RT and NRT traffic for S1 and S2. Then, $D^{S1}_{Conv.}$ and $D^{S2}_{Conv.}$ can be expressed as

$$\begin{aligned} D^{S1}_{Conv.} &= T_{MUE-MBS} + T_{P_{ME}} + T_{MBS-CN} + T_{P_{MBS}} \\ &\quad + T_{MBS-CN} + T_{P_{CN}} + T_{MUE-MBS} + T_{P_{MBS}}, \end{aligned} \tag{1}$$

$$\begin{aligned} D^{S2}_{Conv.} &= T_{MUE-MBS} + T_{P_{MUE}} + T_{MBS-CN} + T_{P_{MBS}} \\ &\quad + T_{Internet} + T_{P_{CN}}, \end{aligned} \tag{2}$$

where $T_{MUE-MBS}$, $T_{MUE-MBS}$, and $T_{Internet}$ are the transmission time between the MUE and serving MBS, between the serving MBS and CN, and between the CN and one of the three network nodes, i.e., serving MBS, serving SAP, and MSs, respectively. Further, $T_{P_{MUE}}$, $T_{P_{MBS}}$, and $T_{P_{CN}}$ are the processing time of the MUE, serving MBS, and CN, respectively.

In the SCN, let D^{S1}_{SCN}, D^{S2}_{SCN}, D^{S3}_{SCN}, D^{S4}_{SCN}, D^{S5}_{SCN}, D^{S6}_{SCN}, and D^{S7}_{SCN} denote the delay of RT and NRT traffic from S1 to S7, respectively. Then, D^{S1}_{SCN}, D^{S2}_{SCN}, D^{S3}_{SCN}, D^{S4}_{SCN}, D^{S5}_{SCN}, D^{S6}_{SCN}, and D^{S7}_{SCN} can be expressed as

$$D^{S1}_{SCN} = D^{S1}_{Conv.}, \tag{3}$$

$$D^{S2}_{SCN} = D^{S2}_{Conv.}, \tag{4}$$

$$\begin{aligned} D^{S3}_{SCN} &= T_{MUE-MBS} + T_{P_{MUE}} + T_{MBS-CN} + T_{P_{MBS}} \\ &\quad + T_{Internet} + T_{P_{CN}} + T_{SUE-SAP} + T_{P_{SAP}}, \end{aligned} \tag{5}$$

$$\begin{aligned} D^{S4}_{SCN} &= T_{SUE-SAP} + T_{P_{SUE}} + T_{Internet} + T_{P_{SAP}} \\ &\quad + T_{Internet} + T_{P_{CN}}, \end{aligned} \tag{6}$$

$$\begin{aligned} D^{S5}_{SCN} = D^{S6}_{SCN} &= T_{SUE-SAP} + T_{P_{SUE}} + T_{Internet} \\ &\quad + T_{P_{SAP}} + T_{Internet} + T_{P_{CN}} + T_{SUE-SAP} + T_{P_{SAP}}, \end{aligned} \tag{7}$$

$$\begin{aligned} D^{S7}_{SCN} &= T_{SUE-SAP} + T_{P_{SUE}} + T_{Internet} + T_{P_{SAP}} \\ &\quad + T_{MBS-CN} + T_{P_{CN}} + T_{ME-MBS} + T_{P_{MBS}}, \end{aligned} \tag{8}$$

where $T_{SUE-SAP}$ is the transmission time between the SUE and serving SAP while $T_{P_{SUE}}$ and $T_{P_{SAP}}$ are the processing time of the SUE and SAP, respectively.

In the SCN with the proposed scheme, let $D^{S1}_{\mathrm{Prop.}}$, $D^{S2}_{\mathrm{Prop.}}$, $D^{S3}_{\mathrm{Prop.}}$, $D^{S4}_{\mathrm{Prop.}}$, $D^{S5}_{\mathrm{Prop.}}$, and $D^{S6}_{\mathrm{Prop.}}$ denote the delay of RT and NRT traffic from S1 to S6, respectively. Further, let $D^{S7,NRT}_{\mathrm{Prop.}}$ and $D^{S7,RT}_{\mathrm{Prop.}}$ denote the delay of NRT and RT traffic for S7, respectively. Then, $D^{S1}_{\mathrm{Prop.}}$, $D^{S2}_{\mathrm{Prop.}}$, $D^{S3}_{\mathrm{Prop.}}$, $D^{S4}_{\mathrm{Prop.}}$, $D^{S5}_{\mathrm{Prop.}}$, $D^{S6}_{\mathrm{Prop.}}$, $D^{S7,NRT}_{\mathrm{Prop.}}$, and $D^{S7,RT}_{\mathrm{Prop.}}$ can be expressed as

$$D^{S1}_{\mathrm{Prop.}} = D^{S1}_{Conv.} = D^{S1}_{SCN}, \quad (9)$$

$$D^{S2}_{\mathrm{Prop.}} = D^{S2}_{Conv.} = D^{S2}_{SCN}, \quad (10)$$

$$D^{S3}_{\mathrm{Prop.}} = D^{S3}_{SCN}, \quad (11)$$

$$D^{S4}_{\mathrm{Prop.}} = T_{SUE-SAP} + T_{P_{SUE}} + T_{Internet} + T_{P_{SAP}}, \quad (12)$$

$$D^{S5}_{\mathrm{Prop.}} = T_{SUE-SAP} + T_{P_{SUE}} + T_{SUE-SAP} + T_{P_{SAP}}, \quad (13)$$

$$\begin{aligned} D^{S6}_{\mathrm{Prop.}} = {} & T_{SUE-SAP} + T_{P_{SUE}} + T_{Internet} \\ & + T_{SUE-SAP} + T_{P_{SAP}}, \end{aligned} \quad (14)$$

$$D^{S7,NRT}_{\mathrm{Prop.}} = D^{S7}_{SCN}. \quad (15)$$

$$D^{S7,RT}_{\mathrm{Prop.}} = D^{S1}_{Conv.} = D^{S1}_{SCN} = D^{S1}_{\mathrm{Prop.}}. \quad (16)$$

3.3 Probability of the mobile data traffic in the CN

In S1, S2, and S3, the MUE communicates with the MUE, MS, and SUE, respectively, and thus there is no mobile data traffic offload for the SCN and SCN with the proposed scheme. In the scenarios from S4, S5, S6, and S7, in the SCN without LIPA and SIPTO, the SAP offloads the mobile data traffic from the SUE to DNs, i.e., MS, SUE, and MUE, but the amount of mobile data traffic in the CN is not reduced even though the SAP offloads the mobile data traffic. On the other hand, the SCN with the proposed scheme can reduce the amount of the mobile data traffic in the CN since the SAP directly transmits the mobile data traffic from the SUE to the DNs using LIPA and SIPTO.

Let $D^{S4-6}_{\mathrm{Prop.}}$ and $D^{S7}_{\mathrm{Prop.}}$ denote the probabilities of the mobile data traffic in the CN for scenarios from S4 to S6 and S7 in the SCN with the proposed scheme, respectively, while D^{S4-7}_{SCN} denote the probability of the mobile data traffic in the CN for the SCN. Then, $D^{S4-6}_{\mathrm{Prop.}}$, $D^{S7}_{\mathrm{Prop.}}$, and D^{S4-7}_{SCN} can be expressed as

$$\begin{cases} P^{S4-6}_{\mathrm{Prop.}} = 1 - P_{SUE} & \text{for S4,S5,S6} \\ P^{S7}_{\mathrm{Prop.}} = 1 - P_{SUE} \cdot P^{NRT}_{SUE} & \text{for S7,} \end{cases} \quad (17)$$

$$P^{S4-7}_{SCN} = 1 \quad \text{for S4,S5,S6, and S7,} \quad (18)$$

where P_{SUE} is the probability of SUEs as SNs in the network while P^{NRT}_{SUE} is the probability of SUEs transmitting NRT traffic. Further, P^{S4-7}_{SCN} is 1 since the SAP always transmits the mobile data traffic to the CN for the scenarios from S4 to S7 in the SCN.

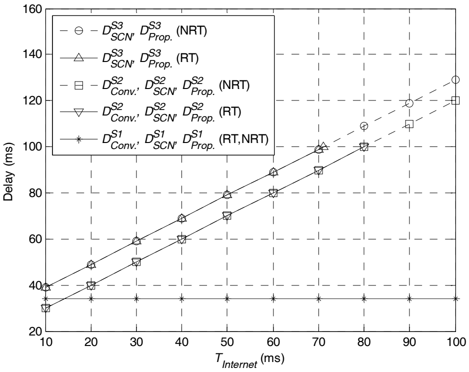
(Table 3) System parameters

Parameter	Value
$T_{MUE-MBS}$	5ms [11]
T_{MBS-CN}	7ms [12]
$T_{SUE-SAP}$	5ms [11]
$T_{Internet}$	10~100ms
$T_{P_{MUE}}$	4ms [11]
$T_{P_{SUE}}$	4ms [11]
$T_{P_{MBS}}$	2ms [12]
$T_{P_{SAP}}$	2ms [12]
$T_{P_{CN}}$	2ms [12]
D^{RT}_{UL}	100ms [13]

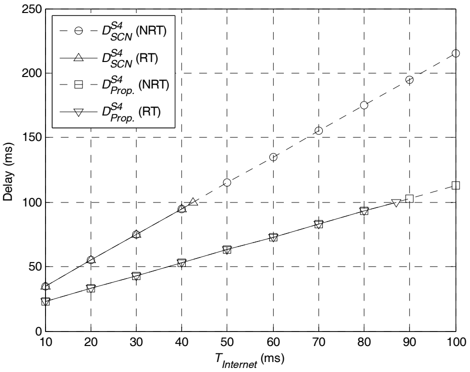
4. Performance Analysis and Discussions

In this section, we investigate the system performance in terms of the delay of end-to-end mobile data communications for the conventional mobile network, SCN, and SCN with the proposed scheme and probability of the mobile data traffic in the CN. The system parameters are listed in Table 3. $T_{Internet}$ is from 10ms to 100ms because the transmission time is variable according to the traffic load on the Internet. Further, D^{RT}_{DL} is the deadline of the delay for RT traffic to drop the mobile data traffic when the delay is over D^{RT}_{DL}.

Fig. 4 describes the results of the delay from the MUE to the MUE, MS, and SUE for RT and NRT traffic in



(Figure 4) The delay from S1 to S3.



(Figure 5) The delay of S4.

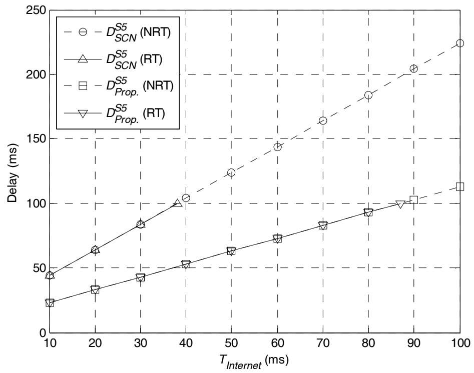
scenarios from S1 to S3. $D^{S1}_{Conv.}$, D^{S1}_{SCN}, and $D^{S1}_{\mathrm{Pr}op.}$ for both RT and NRT traffic are 34ms and there is no change as $T_{Internet}$ increases since MUEs communicate with each other through the serving MBSs of both MUEs and CN (without the Internet). $D^{S2}_{Conv.}$, D^{S2}_{SCN}, and $D^{S2}_{\mathrm{Pr}op.}$ for RT and NRT traffic increase linearly as $T_{Internet}$ increases but $D^{S2}_{Conv.}$, D^{S2}_{SCN}, and $D^{S2}_{\mathrm{Pr}op.}$ for RT traffic increase until $T_{Internet}$ = 80ms because of D^{RT}_{DL}. Further, D^{S3}_{SCN} and $D^{S3}_{\mathrm{Pr}op.}$ for RT and NRT traffic increase linearly as $T_{Internet}$ increases but D^{S3}_{SCN} and $D^{S3}_{\mathrm{Pr}op.}$ for RT traffic increase until $T_{Internet}$ = 71ms because of D^{RT}_{DL}. From the results, it is shown that the delays for S3 are slightly longer than those for S2 since the serving SAP of the DN is added to the path of S3.

Fig. 5 describes the results of the delay from the SUE to the MS for RT and NRT traffic in S4. D^{S4}_{SCN} and $D^{S4}_{\mathrm{Pr}op.}$ for both RT and NRT traffic increase linearly as $T_{Internet}$ increases. However, D^{S4}_{SCN} and $D^{S4}_{\mathrm{Pr}op.}$ for RT traffic increase until $T_{Internet}$ = 42.5 and 87ms, respectively, because of D^{RT}_{DL}. From the results, it is shown that D^{S4}_{SCN} is much longer than $D^{S4}_{\mathrm{Pr}op.}$ since the proposed scheme offloads the mobile data traffic using SIPTO, i.e., the SUE directly communicates with the MS through the Internet. However, in the SCN, the SUE always communicates with the MS through the Internet, CN, and Internet.

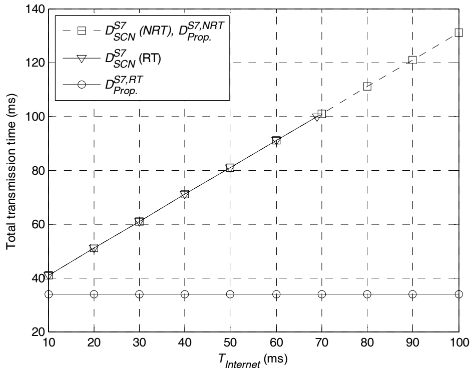
Fig. 6 describes the results of the delay between SUEs that are served by the same SAP for RT and NRT traffic in S5. D^{S5}_{SCN} and $D^{S5}_{\mathrm{Pr}op.}$ for both RT and NRT traffic increase linearly as $T_{Internet}$ increases. However, D^{S5}_{SCN} and $D^{S5}_{\mathrm{Pr}op.}$ for RT traffic increase until $T_{Internet}$ = 38 and 87ms, respectively, because of D^{RT}_{DL}. From the results, it is shown that D^{S5}_{SCN} is much longer than $D^{S5}_{\mathrm{Pr}op.}$ since the proposed scheme offloads the mobile data traffic using LIPA, i.e., SUEs directly communicate with each other through the same serving SAP. However, in the SCN, SUEs always communicate with each other through the Internet, CN, and Internet.

Fig. 7 describes the results of the delay between SUEs that are served by different SAPs for RT and NRT traffic in S6. D^{S6}_{SCN} and $D^{S6}_{\mathrm{Pr}op.}$ for both RT and NRT traffic increase linearly as $T_{Internet}$ increases. However, D^{S6}_{SCN} and $D^{S6}_{\mathrm{Pr}op.}$ for RT traffic increase until $T_{Internet}$ = 38 and 82ms, respectively, because of D^{RT}_{DL}. From the results, it is shown that D^{S6}_{SCN} is much longer than $D^{S6}_{\mathrm{Pr}op.}$ since the proposed scheme offloads the mobile data traffic using SIPTO, i.e., SUEs directly communicate with each other through the Internet. However, in the SCN, SUEs always communicate with each other through the Internet, CN, and Internet.

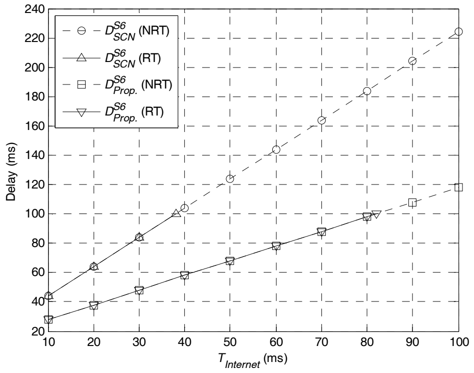
Fig. 8 describes the results of the delay from the SUE to the MUE for RT and NRT traffic in S7. D^{S7}_{SCN} for both RT and NRT traffic and $D^{S7,NRT}_{\mathrm{Pr}op.}$ increase linearly as $T_{Internet}$ increases. However, D^{S7}_{SCN} for RT traffic increases until $T_{Internet}$ = 69ms because of D^{RT}_{DL}. D^{S7}_{SCN} for NRT traffic and $D^{S7,NRT}_{\mathrm{Pr}op.}$ have the same results but D^{S7}_{SCN} for RT traffic is different from $D^{S7,RT}_{\mathrm{Pr}op.}$. That is, $D^{S7,RT}_{\mathrm{Pr}op.}$ always is 34ms



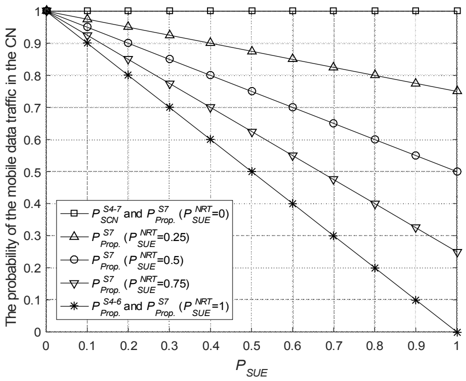
(Figure 6) The delay of S5 (same SAP).



(Figure 8) The delay of S7.



(Figure 7) The delay of S6 (different SAPs).



(Figure 9) The probability of the mobile data traffic for RT and NRT in the CN.

and there is no change as $T_{Internet}$ increases. This is because MUEs communicate with each other through the serving MBSs and CN (without the Internet) after the SUE changes its serving network node from the SAP to the MBS. Thus, D_{SCN}^{S7} for RT traffic is much longer than $D_{\mathrm{Pr}op.}^{S7,RT}$.

Fig. 9 describes the probability of the mobile data traffic for RT and NRT in the CN for the SCN and SCN with the proposed scheme in S4, S5, S6, and S7. In the SCN, P_{SCN}^{S4-7} = 1 even though the SAPs offload the mobile data traffic from SUEs. This is because the SAPs always transmit the mobile data traffic to the CN. On the other hand, in the SCN with the proposed scheme, the SAPs directly transmit the mobile data traffic to the DNs using LIPA and SIPTO for both RT and NRT traffic in S4, S5, and S6 and for NRT traffic in S7 while they transmit the mobile data traffic to the CN for RT traffic in S7. Therefore, from the results, it is shown that P_{SCN}^{S4-7} and $P_{\mathrm{Pr}op.}^{S7}$ with P_{SUE}^{NRT} = 0 are always 1 while $P_{\mathrm{Pr}op.}^{S4-6}$ and $P_{\mathrm{Pr}op.}^{S7}$ decrease linearly as P_{SUE} increases. Further, $P_{\mathrm{Pr}op.}^{S7}$ decreases as P_{SUE}^{NRT} increases from 0 to 1 and $P_{\mathrm{Pr}op.}^{S7}$ becomes the same as $P_{\mathrm{Pr}op.}^{S4-6}$ when P_{SUE}^{NRT} = 1.

5. Conclusions

In this paper, we proposed a dynamic mobile data traffic offload scheme using SAPs with LIPA and SIPTO to reduce the delay of end-to-end mobile data communications for RT and NRT traffic in HetNets. Through analytical models, it was shown that the proposed offload scheme outperforms the conventional SCN in terms of the delay of end-to-end mobile data communications from SUEs to different DNs, i.e., MS and SUE for both RT and NRT traffic but MUE for RT traffic. Further, in the proposed offload scheme, the results of the probability of the mobile data traffic in the CN decreases as P_{SUE} and P_{SUE}^{NRT} increase. However, in S7 for the RT traffic, the SUEs have to change the serving node from the SAP to the MBS and it takes some time for the handover. For future work, we plan to study an enhanced mobile data traffic offload scheme with considering the handover time to improve the proposed scheme for the SCN.

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