Implementation Design of UPCON-based Traffic Control Functions working with vEPC

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Abstract—**To resolve the Radio Access Network (RAN) congestion issue, 3GPP is standardizing a mechanism named User Plane Congestion Management (UPCON) which notifies congestion status information on RANs to Evolved Packet Core (EPC) or behind EPC for efficient traffic control of Long Term Evolution (LTE). This paper presents the implementation design of the traffic control functions (we call them "TCFs") working with virtualized EPC (vEPC). TCF can control traffic in accordance with congestion status information on RANs, which is supposed to be notified by Evolved Node B (eNB) to EPC and its behind systems based on UPCON. We implemented the proposed system as virtual machines working with commercial vEPC software, which includes EPC functions, such as Serving/Packet data network GateWay (S/P-GW) and Policy and Charging Rules Function (PCRF). Through the experimental system, we evaluated the feasibility of TCFs. In addition, we discuss the applicability of TCF to Mobile Network Operators (MNOs).**

Keywords - UPCON; Congestion Control; vEPC; Traffic Control; DIAMETER

I. INTRODUCTION

Since introducing the Long Term Evolution (LTE), the Radio Access Network (RAN) capacity of cellular networks has been expanding dramatically. On the other hand, rich applications, such as high-definition audio/video streaming, image sharing, and online-games have been wide-spreading by which mobile users download rich content via cellular networks. So the traffic volume per user has been increasing dramatically. According to a forecast in [1], from 2013 to 2018, the number of smartphone devices is expected to grow at 18% compound annual growth rate (CAGR) while the mobile data traffic volume is expected to grow at 63% CAGR, i.e., 3.5 times larger. In other words, the growth in traffic volume per user outpaces the growth in the number of devices. Therefore, RAN congestion still remains as a critical issue even if LTE migration is going well [2].

To resolve this issue, the following two solutions easily come up with. First, expanding RAN bandwidth capacity, e.g., by small sizing cells and/or using higher radio frequency is an intuitive and essential solution. However, it requires some processes consuming much time and cost, such as redesign of cells, which may be required again and again corresponding to traffic changes. Second, applying traffic control to congested cells is another solution that just shares the limited bandwidth capacity more reasonably. Although the total capacity does not change, it can improve each user's Quality of Experience (QoE) by preferentially handling critical communications from the other ones and it can more flexibly cope with congestion corresponding to traffic changes. Therefore we focus on the latter solution in this paper.

As for the concrete solutions of traffic control in response to congestion status information on RANs, we roughly categorize them into the following three types. First is that in transport level, e.g., TCP controls the traffic for avoiding congestion in wireless network with lower layer information, where TCP adjusts to the most suitable transmission rate dynamically in accordance with channel status [3]. Second is that based on packet-level QoS scheduling, such as priority queuing. It can provide higher priority communications to users by prioritizing packets generated from specific applications related to the communications [4]. Third is that so-called traffic offload, where (all or a part of) the traffic is redirected to surrounding cells or other types of networks to reduce the traffic in the target cell. For example, Coordinated Multi-Point (CoMP) is standardized by 3GPP release 11 [5], where the congestion level on each Evolved Node B (eNB) is monitored in real time to avoid congestion by load balancing the traffic with surrounding eNBs. In regard to the other types of networks, Wi-Fi or wired network (e.g., FTTH) is used in general.

From the fairness viewpoint between users in a congested cell, traffic control mitigating congestion should not be applied on a *per-flow* (e.g., TCP connection) basis but per *user* (e.g., UE: User Equipment) basis. Moreover, when a UE attaches Wi-Fi, all the traffic from/to the UE had better be offloaded to Wi-Fi, which is another reason for applying per user basis traffic control. In addition, since such other types of networks are being accommodated in Evolved Packet Core (EPC) or behind EPC, traffic control should work in or behind EPC. Hence, a certain mechanism is required by which EPC (or the systems behind it) knows the congestion status information on RANs. 3GPP is now standardizing such a mechanism named "User Plane Congestion Management (UPCON)" [6]. Some use cases of UPCON are proposed in [7][8], such as controlling the traffic at peak time during commuting time, and giving priority accesses for premium users who pay a premium (and expensive) fee. However, feasibility studies on their designs and implementations have not yet been carried out enough.

In this paper, we propose an implementation design of the traffic control functions (hereinafter called "TCFs") working with virtualized EPC (vEPC). TCF can control the traffic in accordance with congestion status information on RANs (hereinafter called "RAN congestion status"), which is supposed to be notified by eNB to EPC and its behind systems based on UPCON. Specifically, our implementation design covers the executions of multiple (and different types of) TCFs independently based on RAN congestion status, which can be retrieved from each TCF with a reasonable overhead. Furthermore, we implemented the experimental system as virtual machines working with a commercial vEPC software [9], which includes EPC functions, such as Serving/Packet data network GateWay (S/P-GW) and Policy and Charging Rules Function (PCRF) [10]. We also evaluated the feasibility of TCFs through the system.

This paper is organized as follows. Section II summarizes the framework of LTE system and UPCON. Section III explains the proposed implementation design of the traffic control functions (TCFs). In Section IV, we evaluate the feasibility of the proposed system, then discuss the applicability of TCF to Mobile Network Operators (MNOs) in Section V. Finally, we conclude the work in Section VI.

II. FRAMEWORK OF LTE SYSTEM AND UPCON

Figure 1 shows an example of LTE system configuration. LTE system consists of UE, eNB, and EPC. EPC includes Mobility Management Entity (MME) and PCRF at Control Plane (C-Plane), and includes Serving data network GateWay (S-GW) and Packet data network GateWay (P-GW) at User Plane (U-Plane). PCRF sets policy rules related to QoS and charging as QoS Class Identifiers (QCIs) and sends them to S/P-GW. Traffic control is conducted based on QCIs. Behind EPC, Application Function (AF) exists in the Packet Data Network (PDN) (e.g., Internet, IMS). Rx interface [11] based on DIAMETER protocol [12] is prescribed between PCRF and AF.

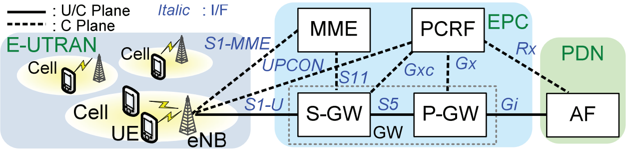

Figure 1. Example of LTE system configuration.

Recently, although the traffic can be controlled in accordance with QCIs set at PCRF in EPC, there has been no standardized mechanism for EPC to grasp the RAN congestion status. In addition, since other types of networks for traffic offload are being accommodated in or behind EPC, traffic control should work behind the accommodation point. Hence, the mechanism called "UPCON" by which the RAN congestion status is notified to EPC or its behind is now being standardized in 3GPP.

In order to further discuss the concrete implementation issues, we suppose that RAN congestion statuses are notified by each eNB, which forms a cell as shown in Fig. 1, and we set the TCFs at AF located behind EPC. In addition, we assume that RAN congestion levels are defined based on each MNO's service operation policy. Since the RAN congestion will occur at the network between an eNB and UEs, i.e., inside a cell, RAN congestion status will vary on a per-cell basis (hereinafter called "*per-cell basis*").

III. TRAFFIC CONTROL FUNCTIONS

As discussed in Section I, TCF should be applied on a per-user basis, while RAN congestion status will vary on a per-cell basis as described in Section II. Thus, we carefully established our design principals of TCF implementation considering how TCF handles relationships between UE and eNB with a reasonable overhead in terms of the data volume and processing time. It should be noted as beyond the scope of this paper that how PCRF obtains RAN congestion statuses from eNBs.

A. Design Principles

First, we established the following design principles.

1. RAN congestion occurs on a per-cell basis. In contrast, TCF assumes that the traffic is controlled on a per-user basis (hereinafter called "*per-UE basis*"), which is practically identified by UE IP addresses. Namely, TCF needs to grasp the RAN congestion level on a per-UE basis. We compared the following notification methods of RAN congestion statuses from PCRF to TCF;
    - Method-1: notify the RAN congestion statuses and information of all the visited UEs in an eNB on a per-cell basis.
    - Method-2: notify the RAN congestion status of each UE accommodated in the TCF, i.e., on a per-UE basis.

   We selected Method-2 because, 1) all the visited UEs in the eNB do not always use the TCF, and 2) when multiple TCFs exist and different UEs are accommodated independently, some overheads on redundant extractions of UEs in the same eNB will occur in all the TCFs if per-cell based notification is applied.
2. RAN congestion statuses are exchanged between PCRF and TCF in accordance with Rx interface. So as to be available for multiple TCFs, a unique Rx session ID, e.g., which is created from the UE's IP address and TCF identifier, is assigned to each UE and TCF pair as a unit.
3. Since each TCF will accommodate different UEs when multiple TCFs exist, a congestion status database (hereinafter called "CDB") for maintaining the congestion statuses of UEs is created in each TCF to keep the size of each CDB as small as possible. The details of CDB are explained in Section III *B*.
4. We consider two types of the notification trigger about RAN congestion status changes in eNBs;
    - Trigger-A: TCF requests RAN congestion status to PCRF periodically.
    - Trigger-B: TCF notifies the status only of UEs relevant to TCF anytime when the RAN congestion status changes in an eNB.

   Since Trigger-A needs to request the RAN congestion status of all UEs registered in CDB,

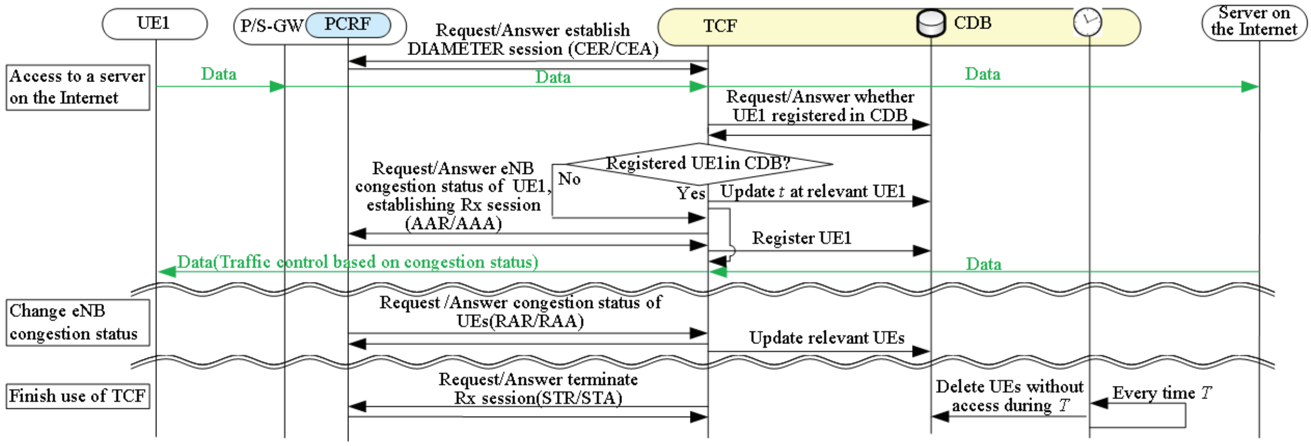

Figure 2. Sequence flow of TCF.

we select Trigger-B, by which a lower volume of RAN congestion status notifications are expected.

5. In the case that the IP address of a certain UE is changed or reallocated to another UE, the CDB ends up storing the invalid RAN congestion status. Therefore, UE data without access for a certain period *T* are deleted from CDB.
6. Whenever the RAN congestion status of UE in CDB is accessed, the corresponding access time *t* on the CDB is updated.

B. Congestion Status Database (CDB)

Table I shows an example of CDB at each TCF. Each record in CDB consists of the UE's IP address, Rx session ID to identify TCF, RAN congestion level *C* at the eNB that UE is now visiting, access time *t*, Cell ID that identifies the eNB, International Mobile Subscriber Identity (IMSI), and Mobile Station International Subscriber Directory Number (MSISDN). When reading a record, the UE's IP address is used as a search key. The values of Cell ID, IMSI, and MSISDN are set based on the obtained information from PCRF.

TABLE I. EXAMPLE OF CONGESTION STATUS DATABASE (AT TCF1)

* CDB key

IP Address*	Rx Session ID	Congestion Level *C*	Access Time *t*	Cell ID	IMSI	MSISDN
IPa	TCF1+IPa	3	*t*1	1	00	aaa
IPb	TCF1+IPb	1	*t*2	2	11	bbb
IPc	TCF1+IPc	2	*t*3	1	22	ccc
:	:	:	:	:	:	:

The CDB accesses occur at three timings (and actions) as shown below.

- *E1*: when a UE accesses TCF (read record and update *t*, or, insert new record)
- *E2*: when a TCF receives a RAN congestion status change at an eNB from PCRF (update *t*)
- *E3*: when a certain period *T* passes from the last access time (delete record)

Note that, at *E2* and *E3* timings, multiple CDB accesses will occur at the same time in proportion to the number of corresponding UEs.

C. Sequence Flow of TCF

The sequence flow of TCF is as follows (see Fig. 2);

1) After a TCP connection between TCF and PCRF is established, a DIAMETER session is established to exchange its identification and functional information (such as protocol version, supported DIAMETER application, and security mechanism) by Capabilities-Exchange-Request/Answer DIAMETER messages (CER/CEA).
2) When a UE accesses a server on the Internet via a TCF, the TCF checks whether the IP address of the UE has already been registered in its CDB. If yes, the TCF updates access time *t* and goes to 5).
3) If no, the TCF sends the UE information (IP address and Rx session ID) to PCRF. The PCRF replies with the congestion status of the eNB that the UE is visiting by AA-Request/Answer Rx messages (AAR/AAA). Then, the Rx session for the UE is established between TCF and PCRF.
4) The TCF registers the UE information, received the congestion level *C*, and access time *t* at CDB.
5) The TCF controls the traffic to the UE based on the congestion level *C*.
6) When the PCRF detects the congestion level changes at the eNB, it sends the corresponding information of the UE and its congestion level to the TCF by Re-Auth-Request/Answer Rx messages (RAR/RAA), and the TCF updates the congestion level *C* of the UE and access time *t*.
7) The TCF finds records in each of which time *T* has been passed from the last access at a constant period *T*, then deletes the matched records from its CDB. In addition, the TCF and the PCRF exchange the termination command by Session-Termination-Request/Answer Rx messages (STR/STA) in order to terminate the relevant Rx session.

IV. EXPERIMENTAL EVALUATION

In order to validate the effectiveness and feasibility of our proposal, we set up an experimental traffic control system on a physical PC (HP DL380p Gen8, 16 core (Intel Xeon E5-26600@2.20GHz), 128GB memory, 400GB HDD, VMware ESXi 5.1), where a commercial vEPC software is running as S/P-GW+PCRF [9] and two types of our developed software are running as TCF1 and TCF2, respectively. We arranged three Virtual Machines (VMs) for S/P-GW+PCRF, TCF1, and TCF2 as shown in Fig. 3. The resources allocated to both TCFs are equivalent, but OSes are different as shown in Table II. The CDB on each TCF is implemented with SQLite3 [13]. The experimental network has two cells. Each cell holds two UEs attached to two types of networks; emulated LTE and Wi-Fi.

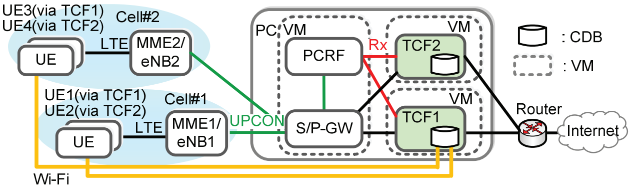

Figure 3. Experimental setup.

TABLE II. VM CONFIGURATION OF EACH TCF

Parameter	TCF1	TCF2
CPU	4vCPU	4vCPU
Memory	28GByte	28GByte
HDD	68GByte	68GByte
OS (Kernel)	Debian 7.1 (3.2.0-4-amd64)	CentOS 6.4 (2.6.32-358.el6.x86_64)

A summary of the traffic control functions is as follows; TCF1 aggregates two types of networks between UE and TCF1, i.e., LTE and Wi-Fi, to obtain higher bandwidth and/or offload the traffic [14]. TCF1 controls the traffic for LTE (it is the target network) based on RAN congestion status *C*. Meanwhile, TCF2 provides a proxy function to aggressively pre-fetch a web content that the UE is expected to access next [15] only when (LTE) RAN is not congested (pre-fetching ON). When (LTE) RAN is congested, such a pre-fetching is not applied (pre-fetching OFF). Note that, we verified the pre-fetching ON/OFF whether the pre-fetch tags are included or not at the header in the downloaded web content.

We set the routing in S/P-GW so that UE1 and UE3 can access the Internet via TCF1, and so that UE2 and UE4 can do it via TCF2.

A. Verification of TCF Behavior based on Congestion Status

First, we verify that the implemented TCFs can control the traffic based on the congestion status *C*. In order to confirm it, each UE accesses the web server on the Internet via the corresponding TCF while the congestion level *C* is varied from 1 to 3 (3 is the most congested) as shown in Table III. In this experiment, UE1 and UE3 via TCF1 start downloading a big size file (763MB) from the web server, UE2 and UE4 via TCF2 access the web server 5 times each in total while *C* changes 1→2→3→1 at eNB1 every 60 seconds.

TABLE III. TCF PARAMETERS AND ACCESS SCENARIOS

TCF #	Function	Congestion level *C* and function ON/OFF	Download files and access timing
1	Control LTE bandwidth	*C*=3 : ON (0.4Mbps) *C*=1, 2: OFF (no control)	Download a file (763MB) from a web server while changing *C*.
2	Pre-fetching	*C*=1: ON *C*=2, 3: OFF	Download Google web content 5 times each in total.

1) Per-UE and per-TCF based traffic control

Figure 4 shows the traffic control results of UE1 and UE2 measured at each TCF when *C* changes in eNB1. In Fig. 4 (a) and (b), the X-axis expresses the elapsed time [sec] and *C* was changed at the times indicated by red arrows.

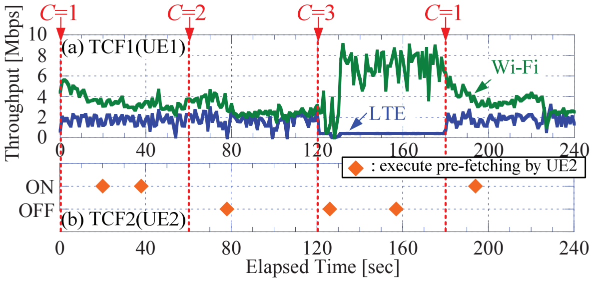

Figure 4. Example of traffic control.

From these plots, TCF can control the traffic based on *C*. As shown in Fig. 4 (a), with UE1 via TCF1, the throughput of LTE changes approximately 2.0→2.0→0.4→2.0 [Mbps]. The LTE bandwidth of UE1 is limited and traffic is offloaded toward Wi-Fi, i.e., traffic control is ON when *C* is 3, while that of UE2 changes to OFF when *C* is 2 and 3. This proves that TCF can control the traffic on a per-UE basis.

In addition, according to the result of UE2 via TCF2 as shown in Fig. 4 (b), the pre-fetching is ON when *C* is 1 and OFF when *C* is 2 and 3, while the throughput of TCF1 in Fig. 4 (a) is almost the same when *C* is varied from 1 to 2, irrespective of the ON/OFF change of TCF2. This proves that TCF1 and TCF2 can control the traffic independently.

2) Per-cell based traffic control

Table IV shows the change of the traffic control status at each UE in cell#1 and cell#2 while *C* changes in cell#1 only. When *C* is varied from 3 to 1, the traffic control statuses at UE1 and UE2 are changed, while those at UE3 and UE4 are kept the same in both ON/OFF cases. Note that there are two cases of OFF→OFF in cell #1 as indicated by red italic characters in Table IV. This reason is that TCF1 is OFF when *C* is 1 and 2, and TCF2 is OFF when *C* is 2 and 3 as shown in Table III. Hence, the TCFs in cell#1 can control the traffic based on *C* in these cases. This proves TCF can control the traffic based on a per-cell basis.

These results including 1) indicate that our proposed implementation design of the traffic control functions is feasible for controlling the traffic based on the RAN congestion status of corresponding UEs by each TCF.

TABLE IV. CHANGE OF THE TRAFFIC CONTORL STATUS AT EACH UE AND CELL (VARIED *C* AT CELL#1)

Cell#	eNB#	UE#	TCF#	*C*1→*C*2	*C*2→*C*3	*C*3→*C*1
1	1	1	1	*OFF → OFF*	OFF → ON	ON → OFF
		2	2	ON → OFF	*OFF → OFF*	OFF → ON
2	2	3	1	OFF → OFF	OFF → OFF	OFF → OFF
		4	2	ON → ON	ON → ON	ON → ON

▇ : Changed traffic control status. *Italic* : Same traffic status in cell#1.

B. Performance Evaluation of CDB

As our proposed system accesses its CDB on a per-UE basis, it is important to perceive the processing performance of the CDB for the number of UEs. To evaluate it, the processing time of CDB at each TCF is measured in four cases; *read*, *insert*, *delete*, and *update*. Specifically, we measure the processing time for accessing *L* records 10 times in each case, where *L* denotes the registration number of UEs (= the number of records in CDB).

Figure 5 shows the processing time at TCF1 and TCF2 when the number of UEs is changed. The processing time is increased in the following the order, *read* < *insert* < *delete* < *update*.

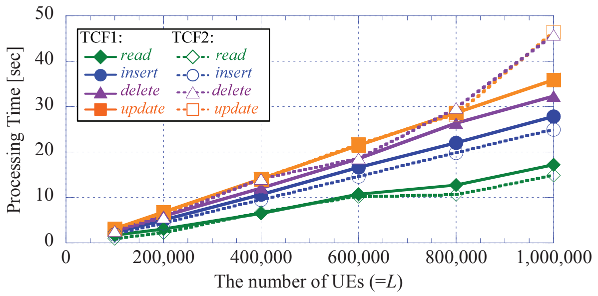

Figure 5. CDB processing time of UEs.

In the case of TCF1, the processing time is (almost) linearly increased as *L* increases. On the other hand, in the case of TCF2, it is also linearly increased when the number of UEs is smaller (*L*<=600,000), but it is rapidly increased when the number of UEs is larger. Specifically, when *L* is 1,000,000, *read* and *update* in TCF1 are 17.17 and 35.85 seconds, respectively, and those of TCF2 are 14.88 and 46.34 seconds, respectively.

According to [16], the system performance of the commercial PCRF is approximately 25,000 [TPS] per server. The processing times of *read* and *update* in TCF are 58,241 and 27,894 [TPS], respectively. This indicates that the performance of TCF is acceptable for practical use.

The *update* processing time is approximately from 2 to 2.5 times longer than *read*. Furthermore, the processing times in TCF1 is shorter than TCF2 at *L*<600,000, whereas it is reversed in *delete* and *update* at *L*>800,000. We assume that this is due to the kernel version because it is the only differential factor between TCF1 and TCF2. This result implies that CentOS is suitable for lower *L*, and that Debian is suitable for larger *L*.

These experimental results indicate that the performance of our proposed system is affected by the *update*, which requires the longest processing time. In addition, the OS (or kernel) selection seems important for achieving good performance at the CDB.

V. DISCUSSION

Based on the results in Section IV *B*, we discuss the applicability of UPCON to MNO. As one example, we refer to Japanese MNO data that indicates the penetration rate in the population of LTE is in the top 3 in the world. Table V shows the number of eNBs and subscribers (i.e., UEs) that MNOs announced in March 2014 [17][18] and the number of UEs per eNB in the Japanese top 3. We analyze how CDB load is carried in regard to the number of UEs and eNBs. We focus on *update* that requires the longest processing time. For simplicity, we assumed that each MNO has one EPC, the number of UEs per eNB is equal in each MNO, a uniform time interval is required to notify the congestion status, and all UEs use the same TCF.

TABLE V. JAPANESE MNOS' DATA

MNO (M_i)	1	2	3
#eNBs (N_i)	97,755	61,062	34,048
#UEs (H_i)	40,522,000	63,105,200	35,924,800
#UEs per eNB (K_i=H_i/N_i)	414.53	1033.46	1055.12

In Table V, M_i (i=1, 2, 3) denotes each MNO. N_i and H_i denote the number of eNBs and UEs at M_i, respectively. K_i indicates H_i per N_i. Let p_{ij} denote the *update* processing time of one million UEs at TCFj (j=1, 2), the per-eNB *update* processing time is given by $K_i \cdot p_{ij}/1{,}000{,}000$, which we denote as v_{ij}. From the result of Section IV *B*, v_{11}=0.015, v_{21}=0.037, and v_{31}=0.038 seconds at TCF1 and v_{12}=0.019, v_{22}=0.048, and v_{32}=0.049 seconds at TCF2, respectively.

Assuming that the congestion status is notified every r seconds from each eNB to PCRF (we call r "notification interval"), TCFj at M_i needs to finish the *update* process within u_i=r/N_i seconds on average, i.e., v_{ij}<u_i.

First, we analyze the effect of r. Figure 6 shows the relationships between r, u_i, and v_{ij}. For instance at M_1, u_1 is 0.037 seconds when r is 3,600 seconds. Here, TCF1 can process *update* because it satisfies v_{11}<u_1. In contrast in the case of r is 600, the *update* cannot be finished within the given time because of v_{11}>u_1. Let R_{ij} denote the threshold value of r by which TCFj at M_i could process *update*, we can easily obtain R_{11} as 1,452 seconds. In the case of TCF2, R_{12} is 1,877 seconds.

Furthermore, for instance at TCF1, in the case of M_2 and M_3, although u_3 is two times as much time as u_2 in order to finish the *update* process, v_{21} and v_{31} are almost the same value because v_{ij} depends on K_i. In addition, in the case of M_1 and M_3, although N_1 is three times larger than N_3, R_{11} and R_{31} are almost the same value because R_{ij} depends on H_i.

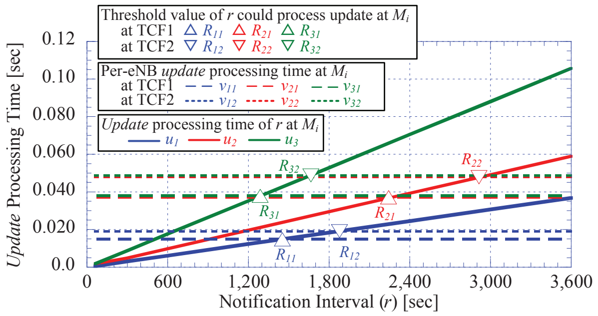

Figure 6. Notification interval of the RAN congestion status from eNB to PCRF vs. *update* processing time.

Next, when the congestion statuses are notified more frequently than R_{ij}, more processing resources are required for TCF, e.g., arranging multiple physical (and/or virtual) machines (we call them "units") for TCF. Hence, we analyze the relationships between r and the number of units for TCFj. Let s_{ij} denote the number of units for TCFj at M_i, and it is given by $s_{ij}=v_{ij}\cdot N_i/r$.

For instance, at M_1 in the case of TCF1, s_{11} is 24.4 units when r is 60 seconds. In contrast, in the case of r is 600 seconds, s_{11} is 2.44 units. Therefore, s_{ij} is an extremely large number when r is short. In the case of TCF2, s_{12} is 31.0 units when r is 60 seconds. In contrast in the case of r is 600 seconds, s_{12} is 3.10 units. Hence, the selection of r and s_{ij} is important.

As one example according to [16], many millions of subscribers are handled by a single PCRF server composed of many blades. Hence, arranging multiple physical machines for TCF seems a practical solution. We leave the effective configuration of multiple servers/blades as future work.

VI. CONCLUSION

In this paper, we propose an implementation design of the TCF working with vEPC. It controls the traffic in accordance with RAN congestion status, which is supposed to be notified by eNB to EPC and its behind systems based on UPCON. Our implementation design covers the executions of multiple TCFs independently based on the RAN congestion status, which can be retrieved from each TCF with a reasonable overhead. We implemented the proposed system with commercial vEPC software, which includes EPC functions, such as S/P-GW and PCRF. The experimental results show that the proposed system can control the traffic based on the RAN congestion status, and demonstrate the performance of CDB. Furthermore, we discuss the applicability of TCF to MNOs about the relationship with the notification time from eNB to PCRF and the number of TCFs. As future work, we will verify that achieving good performance at the CDB to select some OSes (or kernels) and the effective configuration of multiple servers/blades. In addition, we will evaluate the performance of the CDB by varying the number of eNBs and UEs.

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