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TRANSPARENT RAN SHARING OF 5G SMALL CELLS AND MACROCELLS

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ABSTRACT

To cope with the growth of mobile data traffic in 5G systems, telecom operators have to set up more small cells and macrocells in the same area. However, because of space limitations, it is difficult for each operator to do so, and RAN sharing would thus become mandatory for 5G systems. In this work, RANP is proposed, which will achieve transparent RAN sharing by setting up RANP between a base station to be shared and multiple core networks. Over and above the general one-level proxy architecture, an extended two-level architecture is proposed that will share both small cells and macrocells. According to our emulation results, additional packet processing time of a RANP is about 2 ms, 3.8 percent of the total end-to-end latency. Its impact on throughput is about 3 percent and can be regarded as irrelevant.

INTRODUCTION

Because of the increasing popularity of portable devices, the growth of data traffic is inevitable. Notwithstanding traffic growth, cellular systems still need to provide high data rate transmission to individual users, and this is the challenge telecom operators will face in 5G systems. A cellular system consists of the radio access network (RAN) [1] and the core network (CN); in this work, we focus on finding solutions to the RAN. There are two kinds of solutions in 5G systems: spectrum spread [2] and space allocation [3]. In the former, spectrum is treated as a scarce resource for data transmission in a cellular system: the key issue is how to allocate the spectrum efficiently and improve its efficiency. As for space allocation, the challenge lies in how to deploy the cells. In general, deploying more cells means fewer users need to be served by one cell, and each user can transmit at a higher data rate, as long as interference is properly managed. However, because of limitations in some environments, such as buildings, transportation systems, and rural areas, it is difficult or impossible for each operator to deploy as many cells as needed. RAN sharing among operators then becomes an attractive option for operators that cannot satisfy the user requirements with their own cells in 5G systems [4].

RAN sharing has been discussed intensively by the industry as set out in the next section. Vendors, however, tend to adopt an approach of combining a RAN sharing mechanism with their base stations (BSs) in one box, which is called the "integrated box" approach. There are some disadvantages to this approach. First, telecom operators need to replace old BSs with new ones to support the sharing mechanism, which increases their costs. Second, only the operator who owns a shared BS can control it, and other operators have to ask for permission whenever reconfiguration is needed, which constrains operators from adopting RAN sharing. Third, although several RAN sharing scenarios and architectures are defined in the Third Generation Partnership Project (3GPP) [5], the details of RAN sharing are not yet standardized. Therefore, vendors have their own implementations, and telecom operators would depend considerably on the vendors' proprietary products once adopted. For the above reasons, there is a strong need for an "independent box" approach, which implements the RAN sharing mechanism in an isolated box and connects it to BSs and CNs. As a result, we propose "RAN Proxy," following the independent box approach. A telecom operator or a third-party operator only needs to set up a RAN Proxy with minor reconfiguration in the uplink path of the BS to be shared. A RAN Proxy connects to the CNs of multiple telecom operators with secure tunnels, and the BS then becomes shareable. The advantages of our design include:

1. The setup of the RAN Proxy is easier and less costly than the integrated box approach.
2. RAN Proxies can be managed by a third-party operator to ensure independent and fair use among operators.
3. By complying with existing protocols, RAN Proxy is a transparent device that operators can deploy anywhere without affecting the network architecture of fourth generation (4G) or 5G systems.

The rest of this work is organized as follows. The following section provides background and compares works related to our approach. The section after that states the problem, followed by the design of RAN Proxy in the next section. Emulation results in latency, bottleneck identification, and performance testing are then provided, followed by the conclusions and future works.

RELATED WORKS

RAN sharing is not a brand new issue in cellular systems. Huawei [6] and Nokia [7] developed solutions for 2G systems. Huawei proposed a RAN sharing method in the radio network con-

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Papers/patents	Base station modification	Core network modification	Transparent	Hierarchical backhaul	Technology	Device(s)	Uplink routing
Shared RNC [6]	Yes	No	No	No	2G	Shared RNC	CN owning the data flow
Base station sharing [7]	Yes	No	No	No	2G	Logical BS	CN owning the data flow
Multiple gateway [9]	Yes	Yes	No	No	3G, 4G-LTE	HeNB, S-GW, HeNB GW	go home first
NetShare [8]	Yes	Yes	No	No	4G-WiMAX	S-GW	CN owning the data flow
VLAN solution [10]	Yes	No	No	No	4G-LTE	eNB	CN owning the data flow
Brokerage control unit [11]	Yes	Yes	No	No	3G, 4G	BCU	CN owning the data flow
Our proposal	No	No	Yes	Yes	4G and beyond	RAN Proxy	CN owning the data flow

TABLE 1. Comparison of related works.

This new RAN sharing architecture we propose will share both small and macro cells. As for the technology used, we expect this proposal will support 4G and beyond, by just complying with the existing protocols. And, compared to the solutions noted, our proposal is transparent and suitable for 4G and 5G systems.

troller (RNC) called "shared RNC," which could connect to different operators. The BSs could accept different frequencies by configuring the shared RNC, and the user equipment (UE) of different operators could connect to the same BS through different frequencies. Nokia proposed implementing the function in a BS by creating several logical BSs within it to make connections to different CNs. For 3G and 4G systems, NEC [8] proposed a NetShare function in their serving gateway (S-GW). The NetShare function enabled the S-GW to handle the data plane (DP) from different operators, but it did not address the control plane (CP). In another solution for 4G, proposed by Ericsson [9], the home evolved Node B (HeNB) was modified, and an HeNB gateway was added to the CN. The data flow of the CP first went to the HeNB gateway in the CN of the operator owning the HeNB, which was called "go home first." If the data flow of the CP did not belong to the owning operator, the HeNB gateway would compute a new route for the CP and DP. Furthermore, Alcatel-Lucent [10] proposed to slice several VLANs for each operator and made their BSs able to support VLAN function and set up several mobility management entity (MME) IP addresses. It was, however, still highly vendor-dependent. InterDigital [11] proposed the "brokerage control unit" (BCU), which could monitor and control the shared RAN. The BCU communicated with the MME and BS directly by creating new S1 messages, meaning that it was not a transparent solution. Note that none of the studies noted provided numerical results to justify the performance.

In Table 1, these five related solutions are compared in terms of device modification, transparency, involved device, the technology used, and uplink routing, all of which need to modify the BS or CN. As vendors, it is easy to build customized devices. In our proposal, there is no need to add new functions to the BS or CN except some reconfiguration. This means that it is transparent to the network and is an independent box solution. As for uplink routing, in most cases, including our proposal, the data flow goes directly to its own CN. The only exception is "multiple gateway," which adopts "go home first." The other feature of our proposal is supporting hierarchical backhaul. The new RAN sharing architecture we propose will share both small cells and macrocells. As for the technology used, we expect this proposal will support 4G and beyond, just by complying with the existing protocols. And, compared to the solutions noted, our proposal is transparent and suitable for 4G and 5G systems.

PROBLEM DESCRIPTION

General one-level RAN architecture is shown in Fig. 1a. The main goal of this proposal is to render UEs from different operators able to successfully attach to their home CNs through the same shared BS. This can be achieved by properly handling both the CP and DP of the UEs. All of the proposed solutions covered above have to add new functions or components to a BS or a CN and do not strictly follow 3GPP standards. Within the CN, also known as the Evolved Packet Core (EPC) in the 3GPP standard, there are the S-GW, packet data network gateway (PDN-GW or P-GW), and MME. To avoid the disadvantages of previous solutions, we must provide a method that is independent of BSs and CNs, adheres to standards, and does not affect the network architecture of operators. Subject to these constraints, the independent box approach is the best option, and is inserted between BSs and CNs. However, because there is a new node for network traffic to pass through, it is critical to control the delay induced from the independent box. On the other hand, the network architecture, as shown in Fig. 1b, also known as two-level RAN architecture, needs to be addressed with extra care. In two-level RAN architecture, the backhaul is divided into level-1 and level-2 backhaul. Level-1 backhaul refers to the backhaul provided by the small cells set up in the buildings or transportation systems, and level-2 backhaul refers to the backhaul provided by macrocells set up at the roadside or outside of buildings. The CP and DP of level-1 backhaul will be delivered using the level-2 back-

The Independent Box approach we propose in this work is termed RAN Proxy (RANP). Its primary feature is that it is transparent in the network, which means that RANP is not a part of BS or CN, and we set up a RANP without restructuring the network.

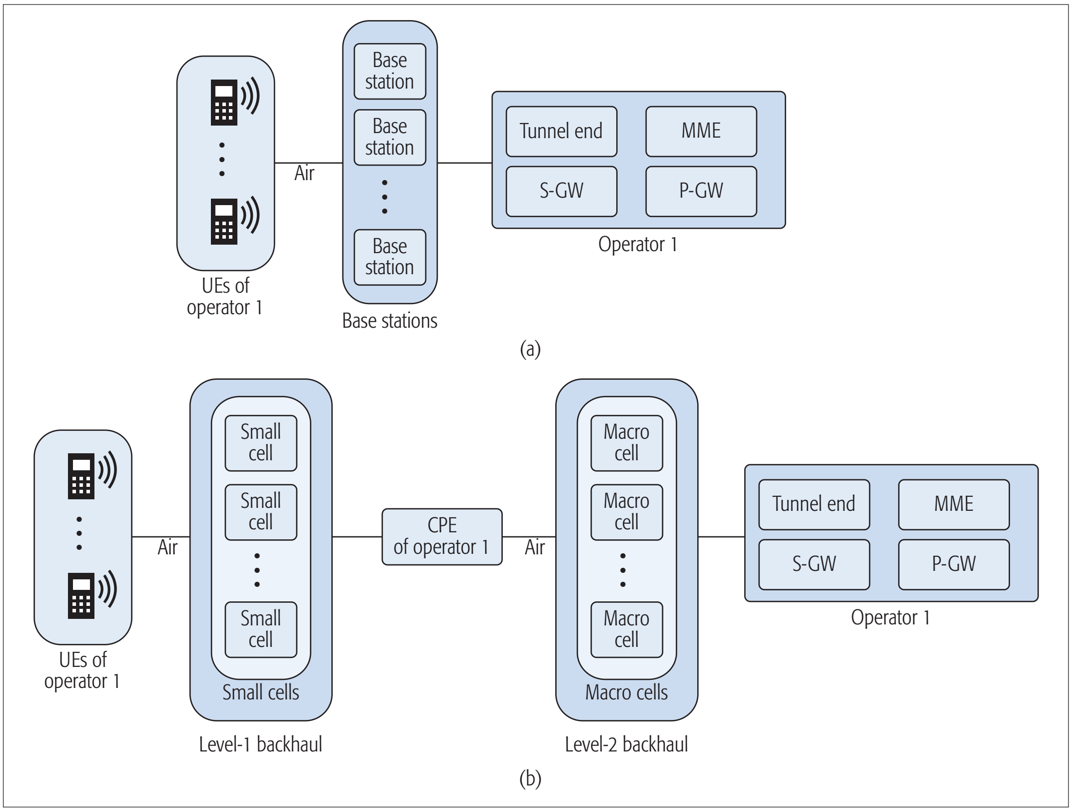

FIGURE 1. Fundamental scenarios without RAN sharing.

haul. In addition to the same issues as level-1 RAN architecture, the sharing of level-1 and/or level-2 backhaul must be flexible.

To sum up, the key issues of the problem are related to how the CP and DP from the UEs are dealt with, subject to specific transparency, delay, and backhaul flexibility constraints, which can be solved by the independent box approach.

THE PROPOSED RAN PROXY

The independent box approach we propose in this work is called RAN Proxy (RANP). Its primary feature is that it is transparent in the network, which means that RANP is not a part of a BS or CN, and we set up a RANP without restructuring the network. The details of RANP design are provided in Fig. 2. In RANP, there are one virtual MME (vMME), and multiple virtual BS (vBS) modules. The vMME is set up as the default MME for the shared BS to receive all S1 messages from it. The vMME will then analyze the non-access stratum (NAS) message and identify the operator of each UE. On the other hand, each vBS is responsible for the communications with the corresponding home CN. A vBS can set up tunnels using the IPsec protocol whenever needed. While one vMME module can serve multiple BSs, each CN should be paired with one vBS module. As for the DP, because general packet radio service (GPRS) Tunneling Protocol (GTP) is used in LTE [12], we propose to use tunnel switching (TS) between BSs and CNs. The TS processes incoming GTP data packets and forwards them to the correct CN once the operator is identified from the S-GW IP address. In RANP, a mapping table is maintained to retain the relationships between UEs and their home CNs. The mapping table can help RANP to obtain the timely status of sharing and trace the operator to which the UE belongs. In summary, with the proposed RANP, RAN sharing can easily be achieved with minor configurations of the shared BSs and involved CNs after setting up RANPs between them.

ONE-LEVEL PROXY ARCHITECTURE

The one-level proxy architecture is designed for general scenarios. If a BS (small cell or macrocell) is connected to a RANP with proper configuration, it can be shared. In this scenario, RANP is responsible for determining how DP and CP packets are transferred to the correct CNs. When necessary, RANP is also responsible for setting up tunnel ending to pair the shared BS with the correct CNs. CP and DP flows are both shown in Fig. 3a. For CP, the packets from UEs will be sent to a BS via the air interface and then processed by RANP. The tunneling from RANP to the tunnel end in the CN is optional, depending on whether the packets should be protected or not. If tunneling is applied, the CP packets could be protected when passing through the shared RAN and sent to the MME directly after the tunnel is terminated. For DP, the packet flow path is similar, and the tunnel is also optional. To be compliant with the 3GPP standards, the destination of the CP and DP is the MME and S-GW, respectively.

TWO-LEVEL PROXY ARCHITECTURE

The two-level proxy architecture is motivated by and used in scenarios where space is limited and wireless/mobile backhaul is required, such as for transportation systems and in buildings. The definition of level-1 and level-2 backhaul is provided earlier. In this section, we detail how this architec-

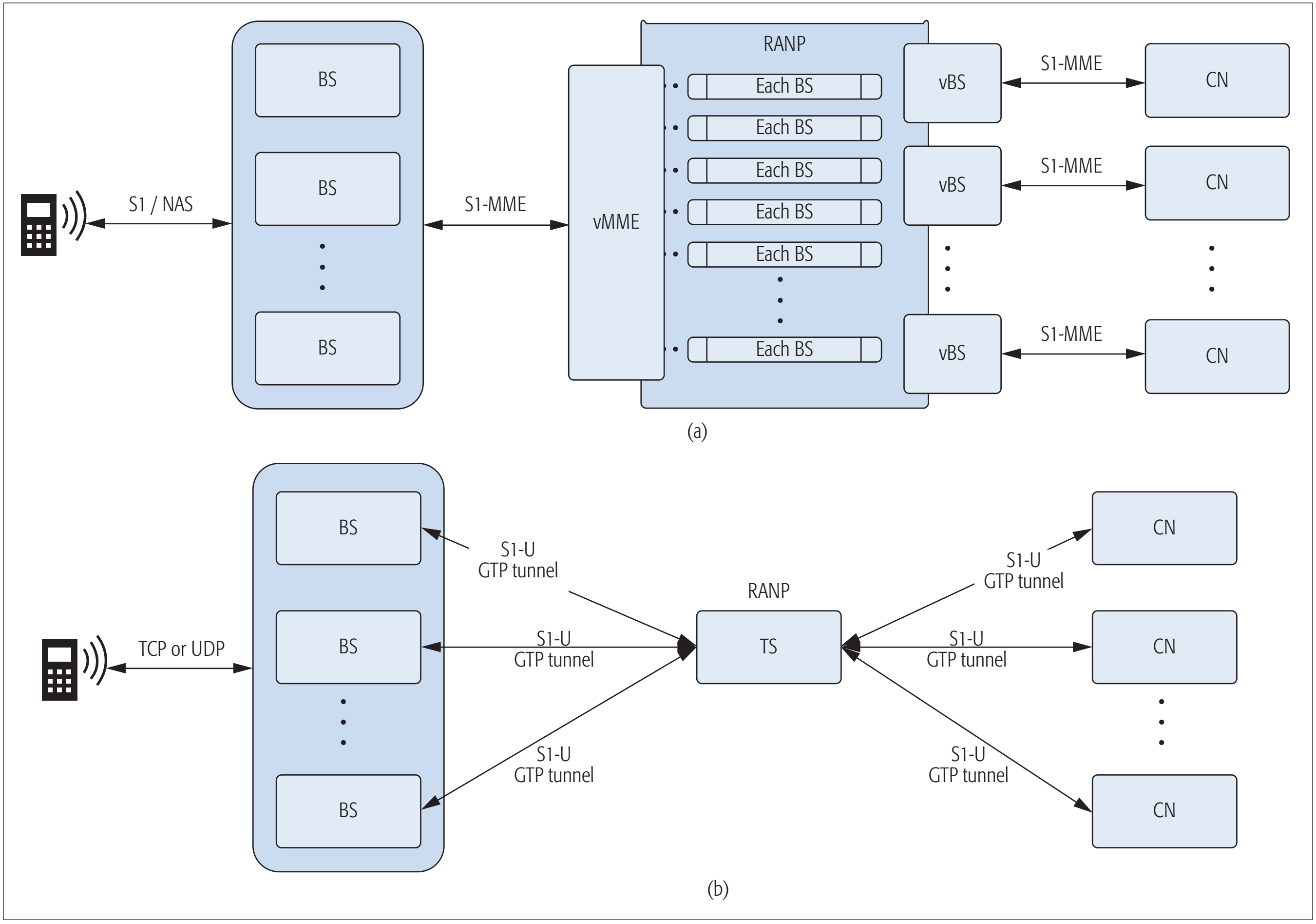

FIGURE 2. RAN proxy design: a) RANP control plane with one vMME and multiple vBEs; b) RANP data plane with tunnel switching.

ture works with two RANPs in terms of CP and DP. Figures 3b and 3c show the packet flow of CP and DP, respectively. In the two-level proxy architecture, the customer premises equipment (CPE) plays the role of connecting the two kinds of backhaul. On one hand, it provides a level-1 backhaul for onboard small cells. On the other hand, it attaches to roadside macrocells providing a level-2 backhaul, and uses the DP of level-2 backhaul to transmit the CP and DP packets of level-1 backhaul. In this architecture, tunneling from level-1 RANP all the way to the home CN is mandatory instead of optional as in one-level proxy architecture, because the DP packets of level-2 backhaul must go through the P-GW and back to the tunnel end in the CN. Note that the other tunneling from the level-2 RANP to the home CN is still optional, similar to one-level proxy architecture. Besides, the CPE is used as a Network Address Translation (NAT) router, and packets can pass through it with the IPsec tunnel mentioned above. There are several variants to this architecture: only level-1 or level-2 backhaul is shared, or both are shared, as shown in Fig. 3. For CP, control packets of UEs will be tunneled by the level-1 RANP, and then transferred through the CPE of the same operator as the UE is detected by the level-1 RANP. When control packets of level-1 backhaul pass through the CPE, they will be packaged as the data packets of level-2 backhaul, and sent to the level-2 RANP. In the level-2 backhaul, the level-2 RANP is also responsible for determining the correct home CN for the packets. When the packets arrive at the home CN, they will be unpacked by the P-GW. Each packet will be routed to its tunnel end in the CN, according to its tunnel tag. Finally, control packets of level-1 backhaul can be received by the MME. For DP, the path is similar to CP. The difference between them is in the CN, where the DP packets of level-1 backhaul will be sent to the S-GW instead of the MME after the tunnel is terminated.

There are two alternative scenarios in two-level proxy architecture: there is either level-1 RANP or level-2 RANP, but not both. We know that all the packets from level-1 backhaul will be sent as a CPE's DP using the level-2 backhaul. In the first scenario, when the CPE of the home operator is overloaded or not available, the level-1 RANP selects the CPE of a foreign operator instead. In the second scenario, since the level-2 backhaul is shared, a CPE can connect to a foreign BS when its home BS is too far or too busy, and this is important for CPEs on, for example, a transportation system. Note that the IPsec tunnel from the level-1 backhaul to the home CN is still necessary as long as a small cell in the level-1 backhaul and a macrocell in the level-2 backhaul are served by the same CN.

RAN PROXY IMPLEMENTATION

The implementation of RANP is based on an Intel Xeon E3-1231 server with 32 GB RAM and CentOS 6 (https://www.centos.org). Python 3 (https://www.python.org) is used for coding. The vMME of RANP adopts multi-thread architecture. For each BS, there are two threads paired to serve it: one for uplink, and the other for downlink. The number of threads in vMME is proportional to the number of BSs. The vBS also adopts multi-thread architecture. Each vBS serves one EPC with only two threads for uplink and downlink. vMME uses sockets to communicate with vBS, and therefore, vBS needs to take up local ports. As for packet analysis, we use the Python library for Stream Control Transmission Protocol (SCTP) connections, analyze the S1 interface based on the Python plugin libmich (https://github.com/mitshell/libmich), and develop NAS interface analysis ourselves. DP is handled by TS, which is a UDP server based on the Python library. Similar to vMME, two threads are paired to serve one BS. However, the TS also needs to communicate with the CN. Finally, IPsec tunnel is implemented with open source Strongswan 5.4 (https://www.strongswan.org).

Numerical Results

Testbed Description

There are two kinds of testbed configurations with reference to the architectures in Fig. 2. The emulation platform for one-level proxy architecture

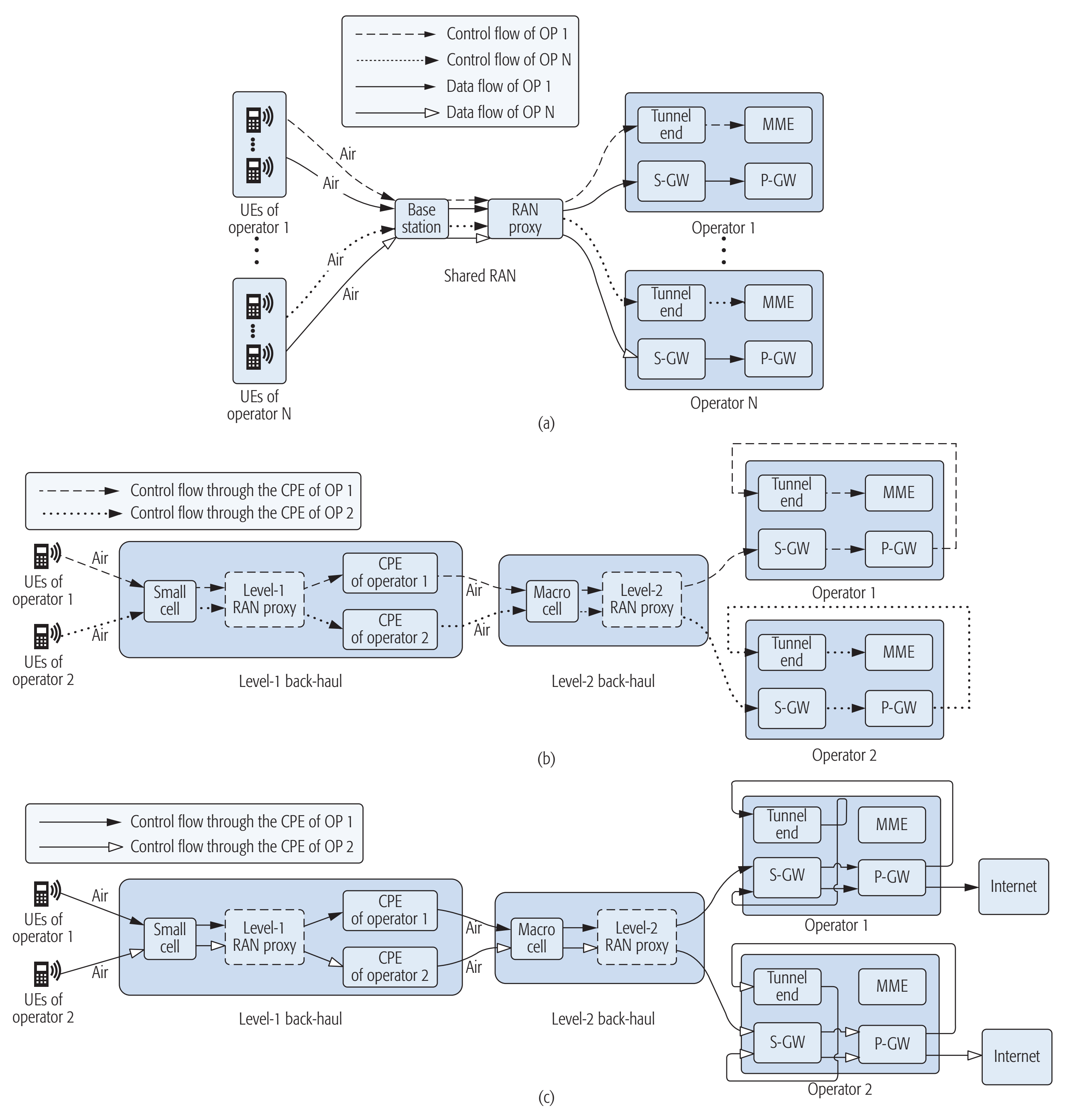

FIGURE 3. Diagram of control/data flow path for proxy architectures: a) control/data flow of one-level proxy architecture; b) control flow of two-level proxy architecture with double RAN Proxies; c) data flow of two-level proxy architecture with double RAN Proxies.

includes a frequency-division duplexing (FDD) macro eNB supporting multiple-input multiple-output (MIMO) mode 2, 15 MHz bandwidth and 64-quadrature amplitude modulation (QAM), two sets of EPC, and a RANP. The two CAT.3 dongles that serve as UE belong to two operators and attach to the eNB via the air interface. All network equipment supports gigabit Ethernet. The S1 interface of eNB, RANP, and EPC go to the same gigabit switch.

On the other hand, for two-level proxy architecture, there are two FDD eNBs, and both support MIMO mode 2 and 64-QAM. The bandwidth in the level-1 and level-2 backhaul is 15 MHz and 10 MHz, respectively. We also set up a CAT.4 CPE, a set of EPCs, and two RANPs. The CAT.3 dongles serve as UE and attach to the level-1 eNB with its level-1 backhaul. The RANP for level-1 backhaul has two network interfaces: one connects CPE, and the other goes to the same gigabit switch as the level-1 eNB. To set up level-2 backhaul, the CPE and the level-2 eNB are separated by two shielding boxes and interconnected by wire. The S1 interfaces of the level-2 eNB, RANP for level-2 backhaul, and EPC go to the same gigabit switch. Level-1 backhaul can be set up only if the DP of level-2 backhaul is set up first.

During the setup of the two-level proxy architecture testbed, some issues arose as a result of the limitations of the equipment. There was only one EPC available, corresponding to a single operator. Furthermore, some configurations of eNBs, such as their bandwidth, are not allowed to be modified because of license conditions. Nonetheless, the sharing ability has been verified in one-level proxy architecture.

RESULTS

RANP is actually a new node inserted into the original network to achieve the desired RAN sharing. The impact of RANP on the network can be assessed from the latency and throughput measurements. Three issues were investigated:

- Whether RANP becomes the bottleneck of CP or DP in the network
- The difference in performance between one-level and two-level proxy architectures
- The possible performance degradation in two-level proxy architecture when level-1 backhaul passes through level-2 backhaul provided by foreign operators

Bottleneck Identification: The bottleneck in the network is investigated in terms of CP and DP, respectively. For CP, we measure the latency of UE attachment and handover procedures with various scenarios in LTE. For the attachment procedure, we also compare the first and second attachment procedures to cover all possible scenarios. Figure 4a shows that the first attachment procedure always takes about 149 ms longer than the second. To gain more insight, we analyzed the attachment procedure by sniffing packets at the RANP and EPC, as shown in Fig. 5. First, we found that the additional 149 ms during the first attachment procedure in Fig. 4a were related to authentication for both the UE and EPC. Using WireShark (https://www.wireshark.org) packets analysis, we found that the authentication process time of EPC in the first attachment procedure was 89 ms, as shown in Fig. 5, while it only took 20 ms in the second attachment procedure. Besides the 69 ms difference, there was another 80 (149 – 69) ms more processing time caused by UE in the first attachment procedure as "c," shown in Fig. 5, since there was more device information to be checked by both the UE and CN in the first attachment. Second, Fig. 5 also shows that the network delay between RANP-vBS and EPC was 10 ms. Therefore, there was a 20-ms network delay in the 353.6 ms (summation from a to y) total latency, and the UE/eNB processing time (c + h + n + s + i + p + u + x) was 333.6 ms. Furthermore, the EPC processing time was 124 (89 + 7 + 28) ms. Compared to UE/eNB and EPC processing time, the RANP processing time was only 17.4 ms, which is 3.8 percent of the end-to-end latency and not a significant portion. In other words, the bottleneck lies in the processing of either UE/eNB or EPC rather than RANP. Note that there were 10 control packets in the attachment procedure for RANP to handle, so the average processing time for each packet was less than 2 ms for RANP.

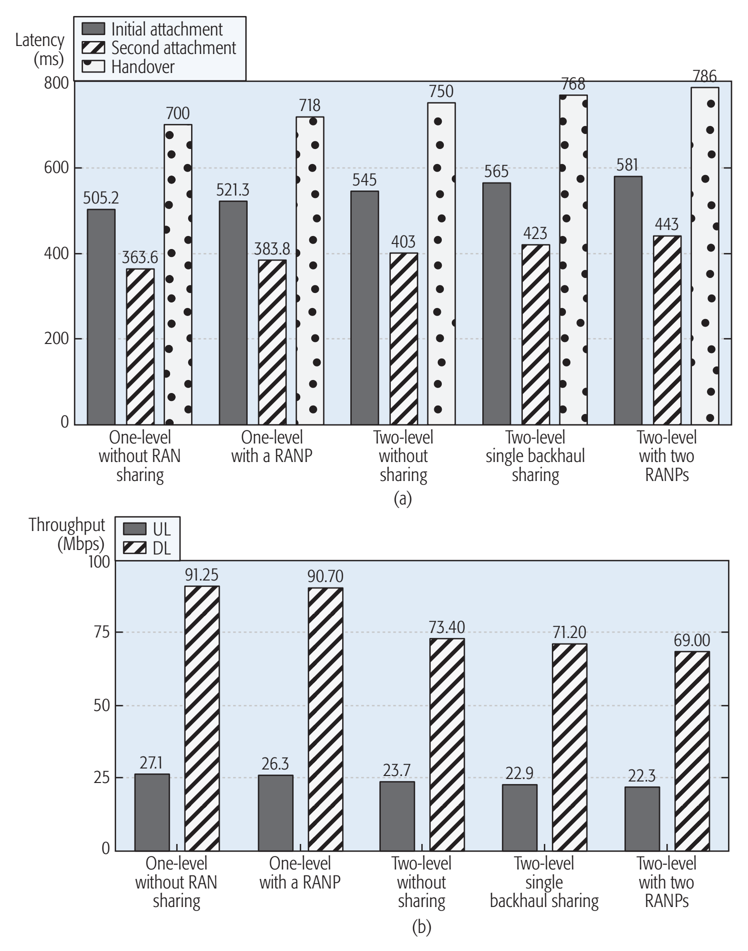

FIGURE 4. Emulation results of the latency for attachment and the throughput: a) comparison of the latency for UE attachment and handover procedures; b) comparison of the throughput for one-level and two-level architectures.

For the handover procedure, we deal with one-level and two-level proxy architecture handover. They are different in the sense that there are CPEs in the two-level case, and they are regarded as normal UEs handing over from one macro BS to another. In our testbed, the S1 handover

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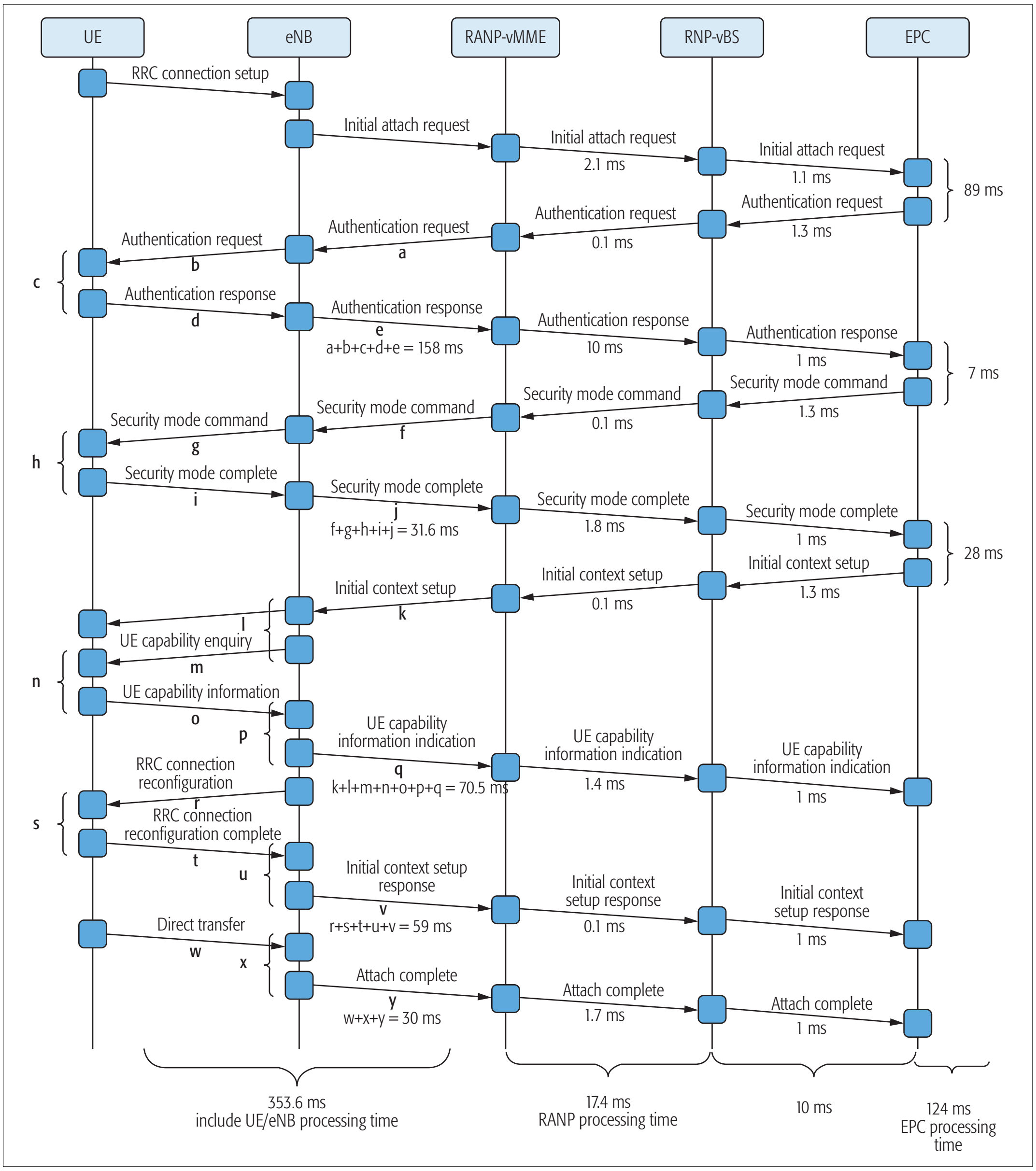

FIGURE 5. Detail of bottleneck identification in the UE initial attachment procedure

procedure was adopted with average handover time about 700 ms through the one-level proxy architecture experiments. As mentioned before, a RANP process time will be less than 18 ms for processing nine messages used in the S1 handover procedure, which corresponds to a 2.5 percent (18/718) increase in latency by a RANP, which is not a significant overhead. Figure 4a shows the comparison of several situations of handover.

As for DP, we used a dongle running the iPerf (https://iperf.fr) utility together with another computer in the network, and the results are shown in Fig. 4b. The ideal throughput of the testbed was 36 Mb/s for uplink and 110 Mb/s for downlink, while the average without sharing proxy was 27.1 Mb/s for uplink and 91.25 Mb/s for downlink. With the same configuration, the average of one-level proxy architecture was 26.3 Mb/s for uplink and 90.7 Mb/s for downlink, or 97 percent of the results without RANP. The impact of RANP on the throughput can therefore be ignored (3 percent), corresponding to the very small difference in Fig. 4b for both one-level and two-level architectures. The difference was caused by the packet header overhead of IPsec tunnels created by the RANP, and determined by its packet forwarding capability.

Performance Difference between One-Level and Two-Level Proxy Architectures: As shown in Fig. 4a, there was about 40 ms more latency for the two-level architecture than for the one-level one. This was due to the network propagation delay and processing time to resolve the IPsec tunnel. According to IPsec tunnel experiments, it takes 0.5–1 ms to resolve one encapsulating security payload (ESP) packet. Since the IPsec tunnel is mandatory in the two-level proxy architecture, the overall latency is inevitably longer than that in the one-level architecture.

The Impact of Passing Foreign Level-2 Backhaul: In the two-level proxy architecture, level-1 RANP will by default select the CPE of the same home operator. However, when the CPE of the home operator is overloaded or unavailable, a level-1 RANP will select the CPE of a foreign operator instead, and the additional latency of about 20 ms can be seen in Fig. 4a. The reason for the additional latency is two-fold. On one hand, the packets going through foreign level-2 backhaul should be routed back to their home EPC. On the other hand, there is a delay related to resolving IPsec tunnels. Note that the variance of the additional latency can be kept small because of the existence of subscriber lines between operators.

CONCLUSIONS AND FUTURE WORK

We have proposed the use of RAN Proxy to achieve RAN sharing transparency, that is, RAN sharing can be realized by adding a RANP between a BS to be shared and multiple CNs with minor configurations. The RANP can be deployed in proximal eNBs to control the latency. The concept is suitable for current 4G systems as well as future 5G systems. According to our emulation results, the processing time of a RANP is about 2 ms, only 3.8 percent of end-to-end latency. Its impact on the throughput is about 3 percent and can be regarded as irrelevant. While the one-level proxy architecture is general and can be broadly applied, the two-level proxy architecture is specifically designed for limited spaces requiring wireless or mobile backhaul, such as moving networks. The two-level proxy architecture has three variants, including sharing level-1 or level-2 backhaul only, and sharing both of them, to better match the diverse requirements in reality.

Despite being promising, there is much work to be done in the future to improve RANP:

- Instead of using a script language, implementing with a lower-level language can further enhance its performance.
- The experiments for the two-level proxy architecture could be more complete with a better equipped testbed
- It is also necessary to test the ability of RANP to serve massive UEs.

Researchers are interested in further enhancing:

- Quality of service of RANP and RAN sharing among UEs of different operators
- Scalability of third-party operations to neutrally operate a large number of RANPs
- Integration of the RANP to 5G systems, such as implementing in the baseband unit pool of the cloud RAN architecture [13, 14] or the mobile edge computing architecture [15] with network slicing technology [4].

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BIOGRAPHIES

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KUN-YI LIN (LinKY@itri.org.tw) received his B.S. and Ph.D. degrees in electrical engineering from National Taipei University of Technology, Taiwan, in 2005 and 2013, respectively. He is currently with ICL, ITRI. His research interests include wireless and digital communications. He is currently working on networking technologies for moving networks and radio-over-fiber system design.

> We have proposed the use of RAN Proxy (RANP) to achieve RAN sharing transparency, that is, RAN sharing can be realized by adding a RANP between a BS to be shared and multiple CNs with minor configurations. The RANP can be deployed in the proximity eNBs to control the latency. The concept is suitable for current 4G systems as well as future 5G systems.