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A D2D communication architecture under full control using SDN

Thanh-Hai Ngo and Younghan Kim
School of Electronic Engineering, Soongsil University
Dongjak-gu, Seoul, 156-743,
[e-mail: {ngothanhhai, yhkim}@dcn.ssu.ac.kr]
*Corresponding author: Younghan Kim

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Abstract

Device-to-device (D2D) communication is a potential solution to the incessant increase in data traffic on cellular networks. The greatest problem is how to control the interference between D2D users and cellular mobile users, and between D2D users themselves. This paper proposes a solution for this issue by putting the full control privilege in cellular network using the software-defined networking (SDN) concept. A software virtual switch called Open vSwitch and several components are integrated into mobile devices for data forwarding and radio resource mapping, whereas the control functions are executed in the cellular network via a SDN controller. This allows the network to assign radio resources for D2D communication directly, thus reducing interference. This solution also brings out many benefits, including resource efficiency, energy saving, topology flexibility, etc. The advantages and disadvantages of this architecture are analyzed by both a mathematical method and a simple implementation. The result shows that implementation of this solution in the next generation of cellular networks is feasible.

Keywords: Device-to-Device, Cellular Network, SDN, Local Connected Network, Direct Communication

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1. Introduction

Device-to-device (D2D) communication is an effective solution to the problems of traffic overload and bottleneck caused by the rapid increase in the number of mobile users and multimedia services. D2D communication promises to bring many benefits including resource-efficiency, higher data rates, lower end-to-end delays, spectrum utilization, coverage extension and so on. It also creates new business opportunities with many notable use-cases, e.g., multicasting, data sharing, game supporting, content distribution, peer-to-peer communications, relaying, public safety services, machine-to-machine communications [1]. To date, Wi-fi direct is the best direct communication technology for mobile devices. However, it requires the user to interact with the phone manually during all phases. It also requires significant energy due to frequency scanning and the channel contention mechanism [2].

Another typical approach to support local communication is forming clusters of cellular mobile devices in which a device takes the special responsibility known as Cluster Head (CH). The CH provides the key functions of a cellular base station. CH distributes synchronization signals, controls radio resources and monitors the mobile users within its cluster. The functions of synchronization provision and radio resource management may reside in the CH or in other devices of the cluster, depending on the radio condition of the CH [3]. Generally, cluster-based approaches have the same drawbacks; i.e., high energy consumption of CH and complicated CH polling and group reformation.

Most studies of D2D have focused on network-assisted D2D communication regarding issues such as interference management, resource and power allocation, etc. The cellular network will support mobile devices with the necessary information via either the broadcast channel or a dedicated channel [4]-[7]. [4][5] provide a brief overview of network-assisted D2D communication. They agree that the network plays an active role in mode selection, resource allocation, power control, scheduling and so on by informing D2D UEs via Layer1/Layer2 control signaling; e.g., the physical downlink control channel (PDCCH). The eNodeB can send two independent PDCCH to both UEs or send only one with a different token, such as C-RNTI. However, channel measurements, reporting and handling of resources for all D2D pairs and cellular UEs may increase the signaling and processing overhead, especially as the number of D2D pairs in the cell increases. The work in [6] reviews and classifies the existing resource control schemes for network-assisted D2D communication. It also proposes an optimization framework for mode selection in consideration of the network performance. These types of study often concentrate on the algorithm to schedule the resource and power for D2D pair but do not mention how to apply these algorithms to the network in detail. They assume that the network monitors all radio environments and has full privilege to make the decisions regarding resources will be used, etc.

An open issue which is being debated by researchers is “using the cellular spectrum or unlicensed spectrum for D2D communication?”. If use the cellular spectrum, it should be considered between overlay approach (dedicated cellular resources is allocated to D2D communications) and underlay approach (Cellular and D2D communications share the same radio resources). In these approaches, the latter one seems to be more efficient in spectrum utilization but the interference between D2D users and traditional cellular user is a big problem that must be overcome. The maximum number of simultaneous D2D transmitters in a cell, thus has to be limited to guarantee the Signal-to-Interference Ratio (SIR). A method to determine this number is proposed in [7]. This problem could be solved if using unlicensed band for D2D communication. However, an effective mechanism to handle the interference between D2D pairs is lacking.

Traffic offloading to D2D communication with the assistance of cellular networks has received considerable attention from the researchers. The authors of [8][9] proposed two prototype approaches; however, like most of the others, they did not consider the interference and radio environment of the D2D communications. These studies also lacked an effective method for data forwarding between the network interfaces of mobile devices. They modified the routing table and connectivity service of mobile devices for this purpose, however, this could lead to failure of traditional Wi-fi direct services.

The appearance of new services for mobile users such as “bring your own device” (BYOD), virtual credit cards, inter-active games and even full high definition streaming leads to a new concept, namely “mobile cloud computing”. Different from conventional static cloud computing models, mobile cloud computing model offloads a portion of computing, traffic to mobile device. It promises to open an effective approach to solve the rapidly growing of traffic, especially in combination with heterogeneous radio access network. The work in [10] proposed a new cloud architecture in which the mobile cloudlet is created by utilizing D2D communication. In order to support mobile cloud computing, it is necessary to develop new mechanism for joint data processing as well as guarantee supplying a reliable D2D connection between mobile devices which is lacking in existing D2D technologies.

To overcome the limitations mentioned above, we propose a solution for Network-Controlled D2D communication using the software-defined networking (SDN) concept. Most control functions for D2D communication will be handled by the cellular network via the SDN controller. The mobile device uses two network interfaces: one for direct communication, and one to maintain contact with the cellular network. Open vSwitch (OVS) and several components are integrated into the mobile terminal to switch data packets between interfaces with session continuity. The interference between D2D pairs will be eliminated by full control by the cellular network. This is achieved because the radio resource for each D2D pair is calculated and assigned completely by the network. The eNodeB does not need to keep track of mobile devices frequently, which reduces the resources used for monitoring. In our proposal, there is no cluster head and no special node. This reduces the overhead derived from the contention for channel and prevents failure due to special node power exhaustion.

This architecture also has a limitation in that modification of the mobile phone is required. The affection of OVS and the additional components on mobile device performance will be examined by a simple implementation in a later section. The paper is organized as follows. Section II describes our proposed design in detail. The benefits and limitations are analyzed and evaluated in Section III. A conclusion is provided in Section IV.

2. Proposed Design

2.1 Overview

SDN is a new paradigm in which the forwarding hardware is decoupled from control decisions. The switches are responsible for handling incoming packets following the instructions from the controller via a southbound application-programming interface (API). We herein apply this concept to support D2D communication. A software switch is integrated into the mobile device to place it under the full control of the cellular network. We aim to develop an architecture that supports establishment of connections between not only two but also multiple mobile clients without the need for Group Owner, Cluster Head etc. Each User Equipment (UE) is assigned an IP address for D2D communication. All UEs in a group must be assigned IP addresses in the same subnet.

Radio resource used for D2D communication may be in a licensed band or industrial, scientific and medical (ISM) band and allocated per D2D pair by the cellular network. These radio resources are expressed in the form of (f,b,t). f, b and t represent the center frequency, bandwidth and timeslot, respectively. An example local network established by our architecture is shown in **Fig. 1**. This local network is suitable for multi-player gaming, local voice and data services, etc.

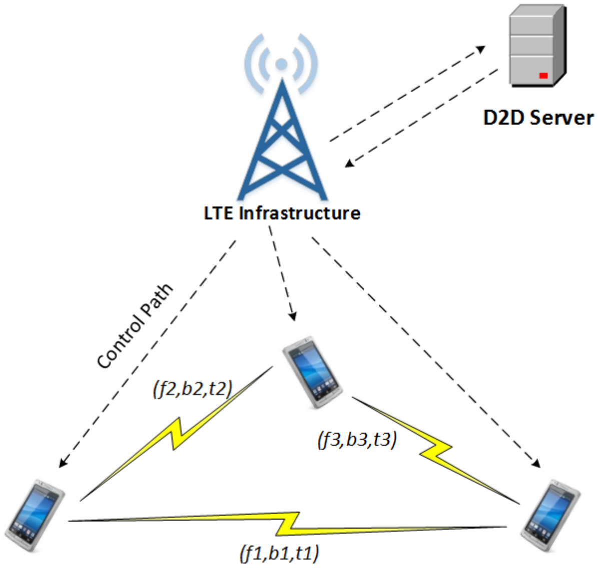

Fig. 1. Local network established by the proposed architecture

2.2 Proposed Architecture

As shown in Fig. 2, our architecture has the following five components: D2D Server, Global Controller, Local Controller, Open vSwitch and RR Mapper.

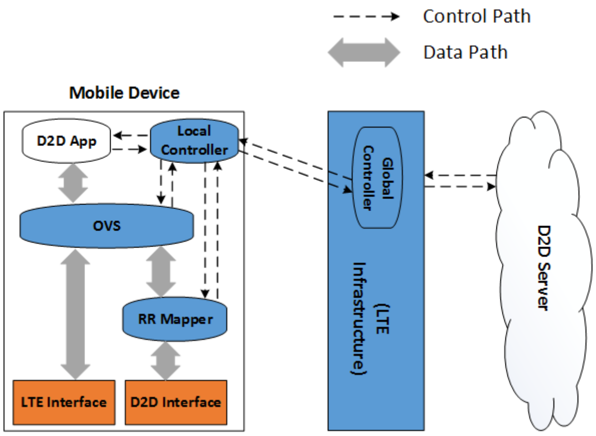

Fig. 2. The proposed architecture

The D2D interface is the physical interface used for D2D communication, for which existing technologies such as Wi-fi and LTE can be used. Details of the D2D interface are outside the scope of this paper. The function and role of the proposed components are described below.

D2D Server is an indispensable logical entity in LTE for supporting D2D communication. In our architecture, D2D Server is responsible for providing the connection between the cellular network and D2D application servers. D2D Server cooperates with Mobility Management Entity (MME), Home Subscriber (HSS), Policy and Charging Rules Function (PCRF) and D2D application servers for functions such as identifying UE proximity, managing D2D device identities and D2D service identities, allocating IP addresses for D2D communication, etc. D2D Server may stand alone or reside in any related entity.

Global Controller is an SDN controller located in the LTE infrastructure. The main responsibility of Global Controller is coordinating with MME to allocate radio resources to each D2D pair. MME receives the coarse-grained decision from D2D Server and determines which available resource can be assigned to each D2D pair. These radio resources may be in an unlicensed or licensed band. Keeping the network-wide state prevents duplicate assignments, and reduces interference and reuse frequency. MME then controls Global Controller to establish the resource policy of Radio Resource (RR) Mapper via the Local Controller. The control plane, which has a two-layer hierarchy, avoids keeping the LTE interface of the mobile device in an active state constantly. A notable framework for control offloading can be found in [11].

Local Controller resides in the user-space of the mobile device. It is responsible for monitoring state and controlling both Open vSwitch and RR Mapper. Local Controller runs as a background service to select a suitable interface for each application. It builds the forwarding rule and determines how a packet should be treated by inserting flow entries into the Open flow table.

Local Controller redirects the policy from Global Controller to RR Mapper, and in the reverse direction queries Global Controller for decisions that require a centralized network state. Local Controller uses Open Flow as an API to interact with OVS and RR Mapper.

Open vSwitch is an enhancement forwarding entity of mobile device. It is used to select a suitable interface for applications and forward packets to the D2D interface in case of D2D communication. Traffic from one application can also be spread over multiple interfaces using OVS. Open vSwitch runs as a kernel module in the kernel space, and generates a virtual bridge with its own address [12]. This IP address will be set as the default gateway for mobile devices. OVS is connected to all other interfaces based on the policy established by Local Controller to forward packets via these interfaces. Similar to all other SDN concepts, the packet will be sent back to the Local Controller for inspection in case it does not match the entries in the existing Open Flow table. OVS also provides per-flow statistic capability based on the counters that can be used to improve Quality of Service (QoS).

RR Mapper also resides in the kernel space of the mobile device. It is responsible for radio resource mapping for D2D flow. Mapper design is dependent on the physical technology used for D2D communication. Thus here we sketch RR Mapper with all requirements and desired features. RR Mapper is an extension of Open Flow switch. Its configuration should be established by the Global Controller via the Local Controller. Base on the result of flow matching, RR Mapper maps the radio resource for each corresponding D2D pair. As mentioned above, these radio resources are expressed in the form of (f,b,t). For this, it must be developed as a resource abstraction layer on the hardware driver of the D2D interface. The study in [13] provides evidence of the feasibility of RR Mapper.

Table 1. An example RR Mapper table

IP Source	IP Destination	Resource Block
192.168.12.1	192.168.12.2	(f_1,b_1,t_1)
192.168.12.1	192.168.12.3	(f_2,b_2,t_2)

See the example in **Fig. 1**, and assume that mobile devices 1, 2 and 3 are assigned IP addresses 192.168.12.1, 192.168.12.2 and 192.168.12.3 respectively. An example resource mapping table is shown in **Table 1**.

2.3 Traffic flow in the proposed architecture

In our architecture, the control plane and data plane are decoupled, as shown in **Fig. 3**.

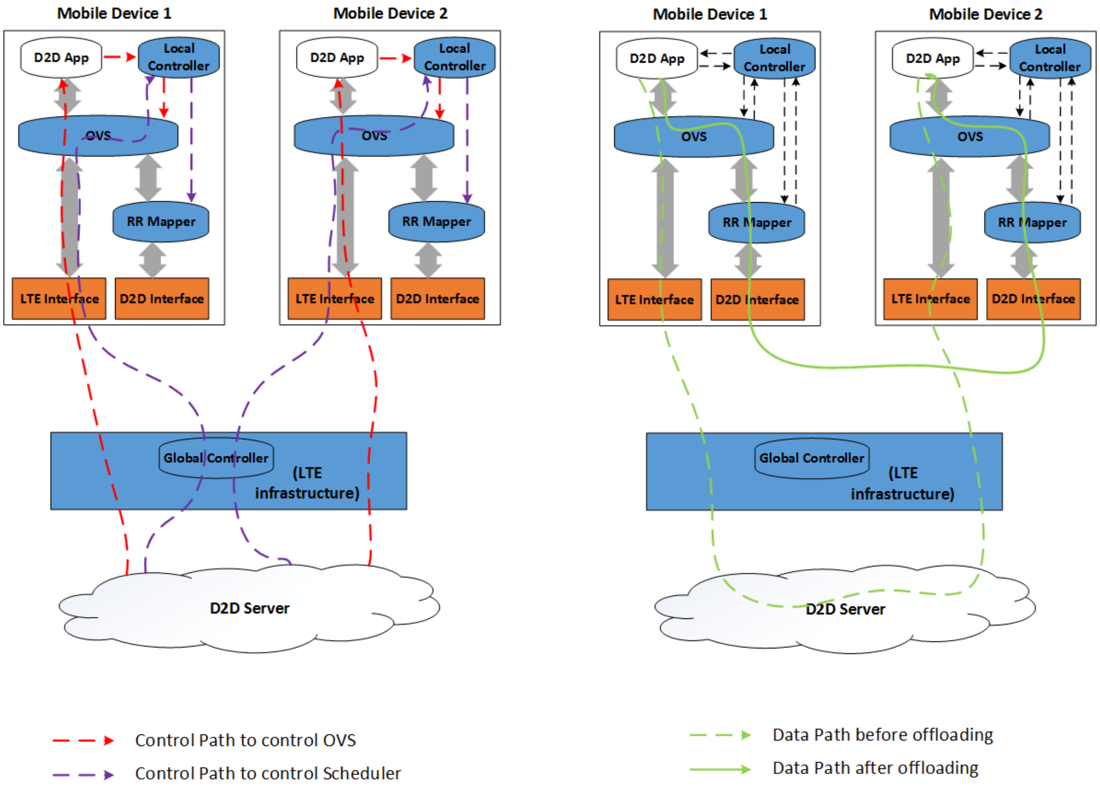

Fig. 3. Traffic flow in the proposed architecture

The image at left shows the control path in our architecture. The red dashed-line represents control flow, which is used to control OVS; the purple line represents control flow used to control RR Mapper. Mobile devices use an LTE interface for sending and receiving control information from/to D2D Server and Global Controller. Because of the stability of LTE, this approach helps to guarantee a connection between the control and data parts.

The image at right shows the data path in the proposed architecture. After the D2D service is activated (herein is an offloading service), data traffic are transmitted directly between two mobile devices using the D2D interface. This path is completely separate with control path. The separation of the control and data planes enables the operator and user to change the topology of the D2D group in a flexible manner.

2.4 Proposed Procedure

To clarify our architecture and support the evaluation in section III, we describe the main procedures used for D2D communication between two mobile devices in detail. Essentially, local connected network with more devices is formed by a set of connections between a pair of devices. So, the procedures for a local connected network are an extension of the proposed procedures described below.

To establish a connection between two mobile devices, first, the procedure "D2D Connection Setup" must be performed. This procedure is illustrated in **Fig. 4**.

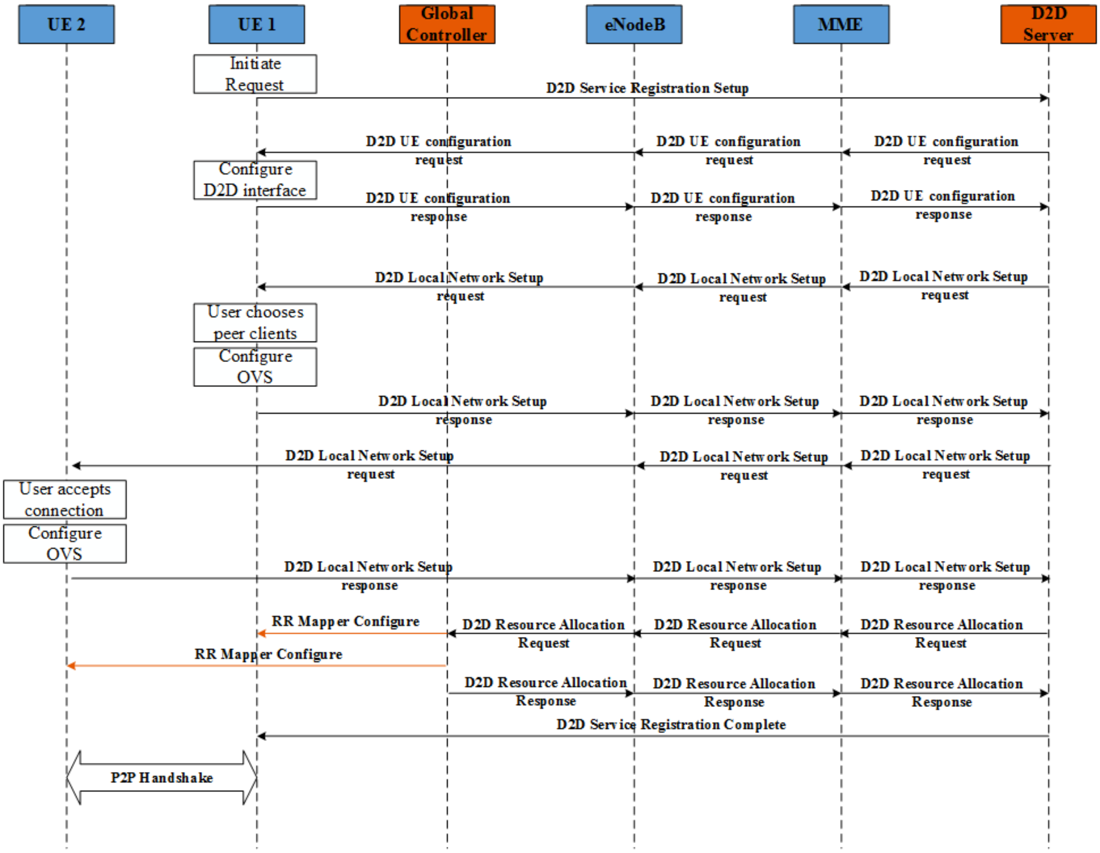

Fig. 4. Procedure for D2D connection setup

We herein assume that the proximity of mobile devices is determined completely by D2D Server with the support of the cellular network. Currently, several services can assist D2D Server to this end, such as satellite-based navigation services (GPS), Location Service provided by the cellular network, etc. The "D2D Connection Setup" procedure starts with initiation from UE1. First, UE1 sends the message "D2D Service Registration Setup" to the D2D Server to register for D2D service. D2D Server then checks subscriber information using the received identities (e.g., IMSI, MAC address of the D2D interface, D2D application service ID, etc.). If accepted, D2D Server assigns an IP address for the D2D interface of UE1 by the message "D2D UE configuration request". After configuring the D2D interface with the assigned IP address, UE1 confirms this to D2D Server by means of a response message. D2D Server then determines which UEs are in proximity to UE1 and sends a list of these UEs with attached information (e.g. IP address) to UE1 via the message “D2D Local Network Setup request”. These UEs are those registered and available for D2D communication. UE1 now selects a peer client (herein, UE2) with which to connect. Simultaneously, UE1 configures OVS for data traffic from D2D Application and confirms this to D2D Server via the message “D2D Local Network Setup response.” D2D Server will inform UE2, and if UE2 accepts, it will configure its OVS to ensure that the data flow between UE1 and UE2 passes through the D2D interface. A confirmation is sent to D2D Server. After receiving the confirmation from both UE1 and UE2, D2D Server coordinates with MME to allocate the radio resources for the UE1-UE2 connection. MME then configures RR Mappers of UE1 and UE2 via Global Controller and sends a confirmation to D2D Server. Finally, D2D Server can inform UE1 of the success of registration via the message “D2D Service Registration Complete.” UE1 and UE2 now perform a P2P Handshake to transmit the packet.

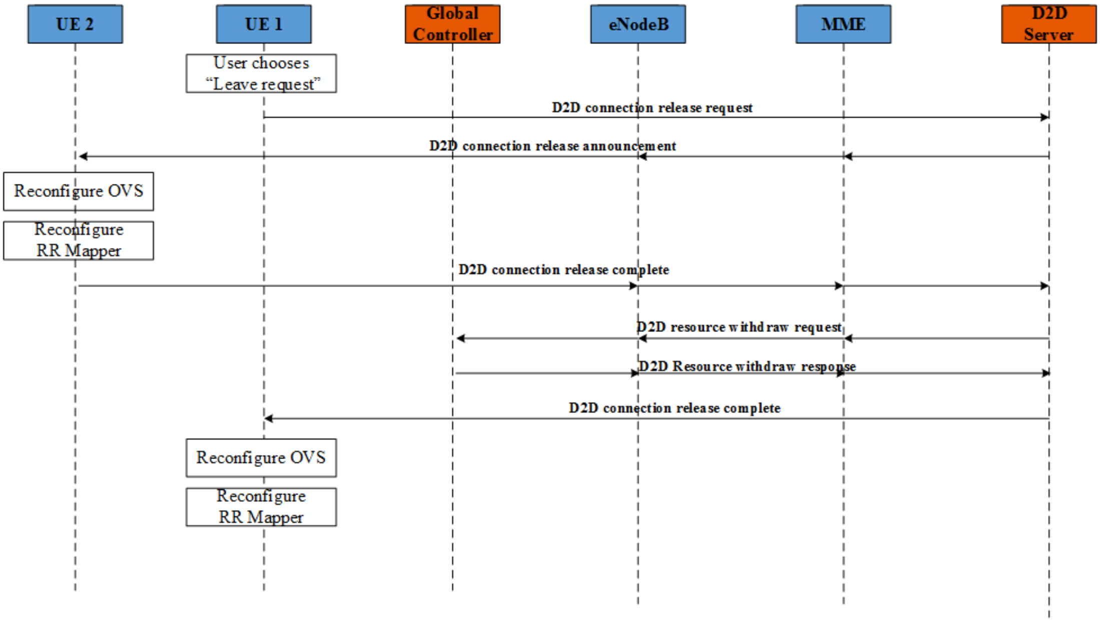

Fig. 5. Procedure for D2D connection release initiated by the user

In P2P handshake phase, two UEs exchanges the probe signals to inform their presences to each other. The probe signal is a number of frames that provide the information to UE regarding the identifier, signal strength, supported data rates, etc. Assuming that the cellular network provides the synchronization between UE1 and UE2, if there are no data to transfer between two UEs, they will turn to sleep mode. Two UEs wake up periodically after a pre-defined interval to listen for the probe signal. When UE1 has a packet to send to UE2, it sends a Probe Request to inform UE2. Based on the received Probe Request, UE2 calculates the received signal power and compares it with a pre-defined value to ensure that the two UEs are still in proximity. If satisfied, it will send a Probe Response to UE 1. After the authentication phase, they can send data traffic to each other. If there are no data transferred for a timer, both switch to sleep mode. If a given time elapses in sleep mode, the D2D connection is released.

To release the D2D connection, the UE will execute “D2D connection release” procedure. Fig. 5 describes the procedure for D2D connection release initiated by the user. The release procedure initiated by the network is similar but the “D2D connection release request” from UE1 is skipped. After receiving the release request from UE1, D2D Server announces to UE2. Base on this announcement, UE2 removes all configurations in its OVS and RR Mapper relating to UE1 and confirms this to D2D Server via the message “D2D connection release complete.” D2D Server now updates its database and informs MME to withdraw the radio resources allocated to the UE1-UE2 connection. Finally, after receiving the confirmation from MME, D2D Server informs UE1 via the message “D2D connection release complete”, and UE1 completes removal of all D2D-related configurations in its OVS and RR Mapper.

If the direct connection between two UEs becomes worse, the communication between them can be switched back to the cellular network. The diagram in Fig. 6 shows this procedure.

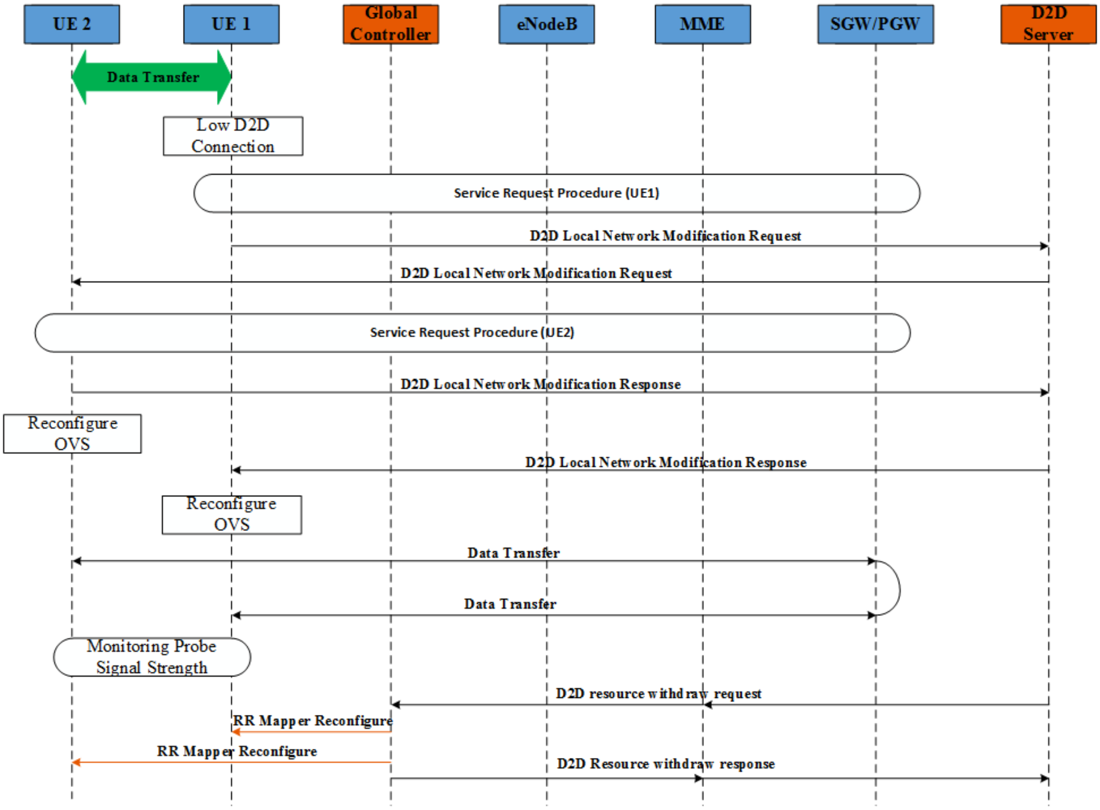

Fig. 6. Procedure for switching from D2D to cellular communication

We suggested a solution in which UEs must monitor the quality of the D2D connection and themselves recognize a low connection state. When a UE discovers this situation, it will initiate the "Service Request Procedure" to the cellular network for bearer establishing. This is necessary because the LTE connection became inactive after a prolonged period. "Service Request Procedure" follows The Third Generation Partnership Project (3GPP) standard for LTE networks. After completion of the Service Request, UE1 requires the D2D Server to modify its local network by sending the message "D2D Local Network Modification Request." D2D Server then checks the database and forwards the request to UE2. UE2 must also perform the Service Request Procedure to establish LTE bearer for itself and inform the D2D Server of successful completion.

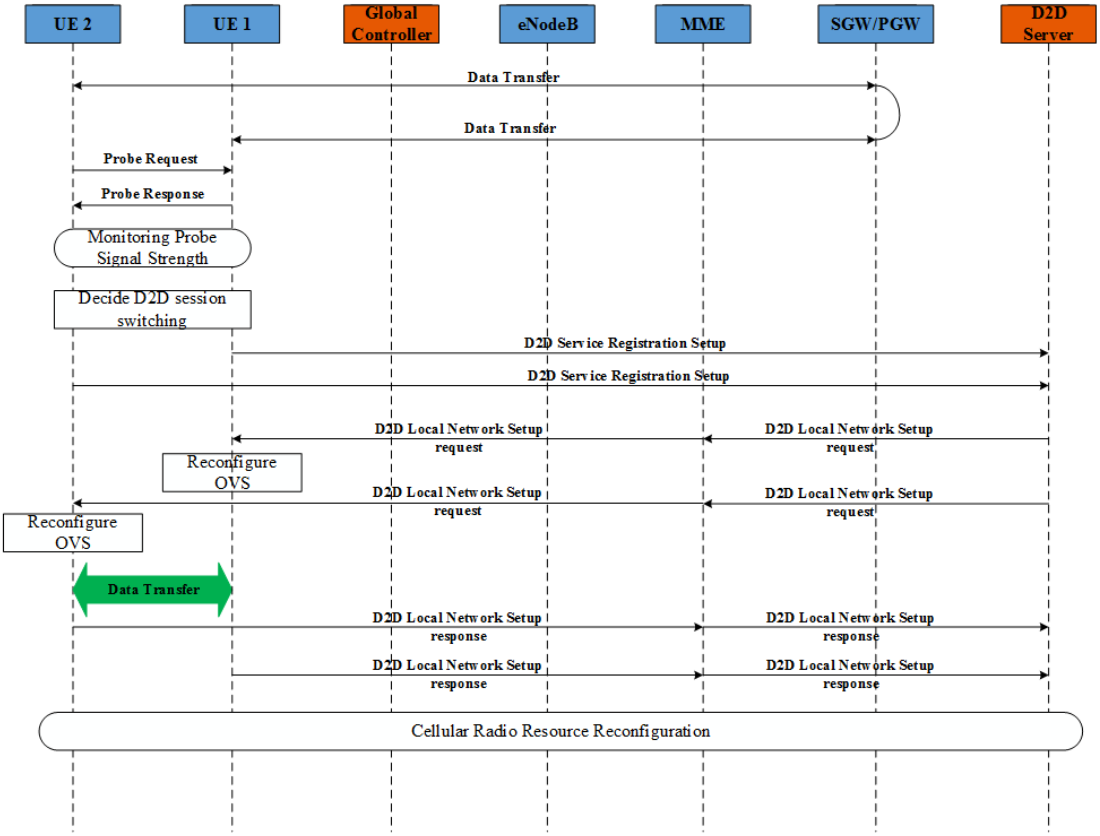

Fig. 7. Procedure for switching from cellular to D2D communication

Simultaneously, UE2 reconfigures its OVS to use the LTE connection for communication with UE1. At this time, D2D receives confirmation of UE2, and sends the message "D2D Local Network Modification Response" to UE1. UE1 then reconfigures its OVS to use the LTE connection for communication with UE2. Two UEs now can communicate with each other via the LTE connection. The two UEs monitor Probe Signal

Strength for a period of time. D2D Server starts a timer corresponding with this period. If after the timer expires, D2D server does not receive a request from UEs to re-establish D2D communication, it will update its database and inform MME to withdraw the radio resource allocated to the UE1-UE2 connection. MME will coordinate with Global Controller to reconfigure the RR Mappers of UE1 and UE2.

In contrast, if the radio condition for D2D communication improves, UE1 and UE2 can send a request to D2D Server to switch back the connection from the cellular network to direct D2D communication. The procedure for this is shown in **Fig. 7**.

The decision to switch back to D2D communication must be made by both UE1 and UE2. When messages “D2D Service Registration Setup” are received from both of them, D2D Server sends the message “D2D Local Network Setup request” to each UE to instruct them to reconfigure their OVS. The UEs can then transfer data directly via the D2D interface, and a confirmation is sent to D2D Server. The bearer of the LTE connection should be modified by the LTE standard procedure.

3. Evaluation

In this section, we analyze the advantages and disadvantages of the proposed architecture and evaluate it using both mathematical and implemental methods.

Using the SDN concept, we place the control functions for D2D communication in the cellular network. This makes D2D communication more transparent to the mobile users and enables the operator to implement data offloading services. The radio resources for each D2D pair are allocated centrally. This prevents interference, and reduces the delay and overhead derived from resource contention. Our architecture allows two mobile devices to communicate with each other without a group owner. They can communicate directly without traversing other nodes. All drawbacks of conventional technology, such as power exhaustion in group owner node and single failure point, are resolved. Moreover, the hierarchical control system obviates the need to keep the LTE interface of the mobile device in an active state.

Open vSwitch, which is integrated into mobile devices, brings many benefits. It guarantees session continuity when switching data between many interfaces by creating a virtual switch in the mobile device, which functions as the default gateway for the device. This switch is the middle point for all network interfaces. Without OVS, the destination IP address of packets will change when the interface changes. It is the reason of the session interruption. Open vSwitch allows processing of user data at the flow level, and helps to control QoS and traffic statistics.

Beside the benefits, the limitation of this architecture is the requirement for modification of the mobile terminal. This can increase energy consumption and delay in the mobile terminal. We evaluate the effect of Open vSwitch and the additional components on mobile device performance using a simple test bed in part C. The benefits of energy consumption and signaling load reduction are evaluated by a mathematical method in parts A and B.

3.1 Energy consumption

With our design, the network maintains a global view and assigns radio resources to each D2D pair. Thus use of an ISM band is suitable but still possible to control the interference between D2D pairs. We herein consider using Wi-fi direct for D2D communication and compare the energy consumption of mobile device in our architecture with other approaches, such as [8][9].

To simplify the evaluation, we calculate only the energy used to receive a downlink stream by a mobile device. First, we consider the simple model in [14]. In this model, the average time needed to receive one packet is denoted as:

$$T_{data} = \frac{CW_{\min}}{2} + T_{PS\_POLL} + 2SIFS + T_{packet} + T_{ack} + DIFS$$

$CW_{\min}$ is the minimum value of the contention window. T_{packet}, T_{PS_POLL}, T_{ack} are the time taken to receive a packet, receive *PS_POLL* and *ACK* signal respectively. *SIFS* (Short interframe space) and *DIFS* (Distributed coordination function interframe space) are standard intervals used in CSMA/CA (Carrier sense multiple access with collision avoidance) which is the multiple access method of IEEE 802.11b WLAN.

Let λ denote the packet arrival rate of the sending node, which follows a Poisson distribution. I_b is the beacon interval. M is the total number of nodes in the network. The number of buffered packets in the access point at the *i* th beacon interval is denoted as follows:

$$\alpha_i = \mathrm{M}\, \lambda\, I_b$$

β_i is the number of nodes that receive a buffered packet in the AP at the *i* th beacon interval. We have

$$\beta_i = M(1 - e^{-\lambda I_b})$$

In the *i* th beacon interval, the waiting time for a node to receive the buffered packet is:

$$T_{wait,i} = T_{data} \frac{1}{\alpha_i} \sum_{j=1}^{\alpha_i - 1} j = \frac{1}{2}(\alpha_i - 1) T_{data}$$

E_{idle}, E_{active} *and* E_{sleep} is power consumption per second by IEEE 802.11 WLAN network interface in idle, active and sleep mode respectively and is referred from [17]. The total power consumption during the *i* th beacon interval is denoted as follows:

$$E_i = T_{wait,i} E_{idle} + \frac{\alpha_i}{\beta_i} T_{data} E_{active} + (I_b - T_{wait,i} - \frac{\alpha_i}{\beta_i} T_{data}) E_{sleep}$$

In our architecture, because the radio resources are allocated to each pair by the cellular network, the RTS/CTS and distributed coordination function (DCF) are eliminated. So, the average time needed to receive one packet is: $T_{data} = T_{packet} + T_{ack}$

The following formulas are used to calculate α_i and E_i in our case:

$$\alpha_i = \lambda I_b$$

$$E_i = \alpha_i T_{data} E_{active} + (I_b - \alpha_i T_{data}) E_{sleep}$$

Values of related parameters refer to the values of IEEE 802.11b WLAN, and are shown in **Table 2**.

Table 2. Evaluation parameters

Parameter	**Value**
M	10
Packet length	1000 bytes
PS_POLL size	24 bytes
Transmission rate	2 Mbit/s
I_b	50 ms
CW size	32
T_{ack}	60 µs
SIFS	10 µs
DIFS	50 µs
E_{idle}	843.72 mW
E_{active}	966.96 mW
E_{sleep}	66.36 mW

Fig. 8 and **Fig. 9** show the result of comparison. Our architecture reduces energy consumption by ~50% in comparison with the similar approaches that use traditional WLAN 802.11 technology for D2D communication.

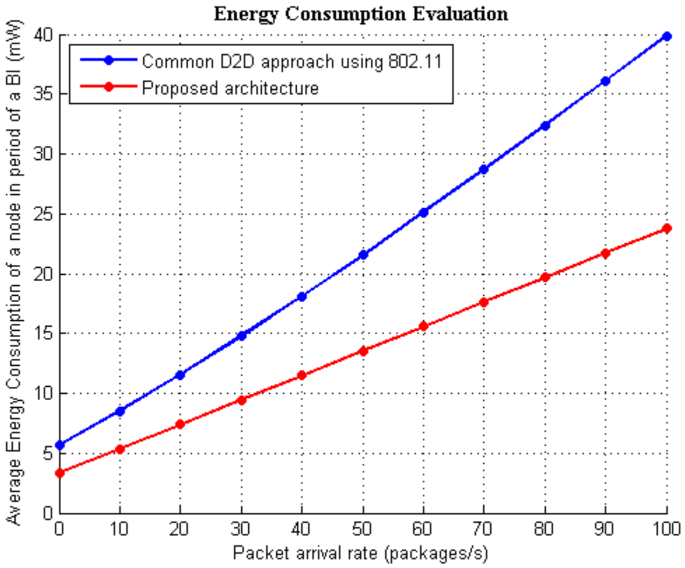

Fig. 8. Comparison with two nodes in the network

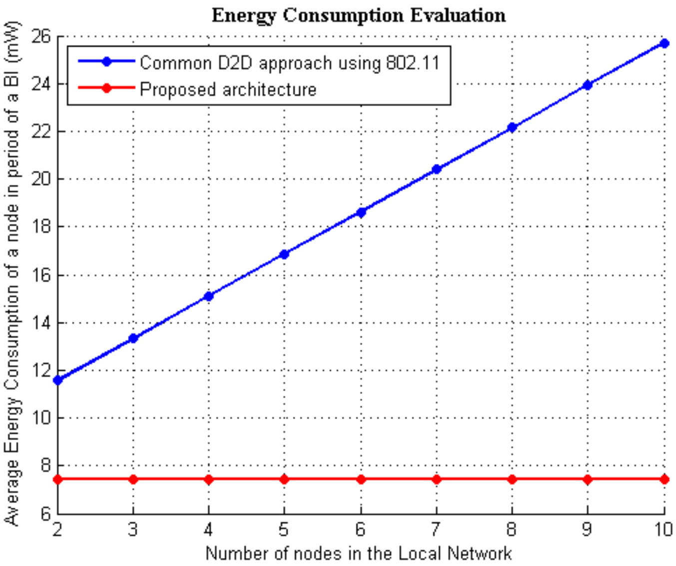

Fig. 9. Comparison for a packet arrival rate of 20 packets/s

3.2 Signaling Load

This part compares signaling load in an eNodeB between our architecture and the work in [14], which is a typical approach to D2D communication with network partial control. To simplify, we only evaluate Signaling Load due to D2D communication setup procedure and assume that D2D communication is only established in an area of one eNodeB.

Let P_{d2d} denote the probability that the D2D interface is used by a UE. ρ is UE density (UEs/km^2). S is the coverage of an eNodeB (km^2). d is the maximum distance for a D2D service. We infer that the D2D range (denoted s) is given by $2\pi d^2$. We assume that each UE supports k application types, as in the model in [16]. λ_k is the average arrival rate of session type-k at a UE (session/hour/UE). μ_k^{-1} is the average duration of session type-k. Pr{Ok} denotes the probability that a type-k session is originated by a UE.

Let p_I be the probability that UE is in an IDLE state. The probability that UE is in a CONNECTED state is (1- p_I). From [15], the formula to calculate p_I is given by

$$p_I = \prod_{k=1}^{K} \left(\frac{\mu_k}{\mu_k + \lambda_k}\right)$$

Assume that the probability of successful D2D establishment is equal to the probability of two active D2D-enabled UEs given by

$$P_{success} = 1 - P(X=0) - P(X=1)$$
$$= 1 - \frac{a^0}{0!} e^{-a} - \frac{a^1}{1!} e^{-a} = 1 - (a+1) e^{-a}$$

P(X) follows the Poisson distribution with a= $\rho.s.P_{d2d}.(1- p_I)$

The average number of UEs that result in successful D2D communication in the coverage of an eNodeB is given by

$$N = \rho.S.P_{d2d}.(1- p_I).P_{success}$$

The total messages processed at eNodeB per hour due to D2D communication initiated by type-k application (except Web browsing) in our architecture is given by:

$$N1 = 8.\lambda_k.Pr\{Ok\}.\rho.S.P_{d2d}.(1- p_I).P_{success} + 4.\lambda_k.Pr\{Ok\}.\rho.S.P_{d2d}.(1- p_I).(1- P_{success})$$

In [14], a D2D device initiates D2D communication setup when it is certain of the presence of the peer device. Consequently, the total messages processed at eNodeB per hour due to D2D communication initiated by type-k application (except Web browsing) is given by:

$$N2 = 14.\lambda_k.Pr\{Ok\}.\rho.S.P_{d2d}.(1- p_I).P_{success}$$

Via numerical calculation, our architecture reduces signaling load in eNodeB in comparison with the work in [14]. The detail is shown in **Fig. 10** and **Fig. 11**.

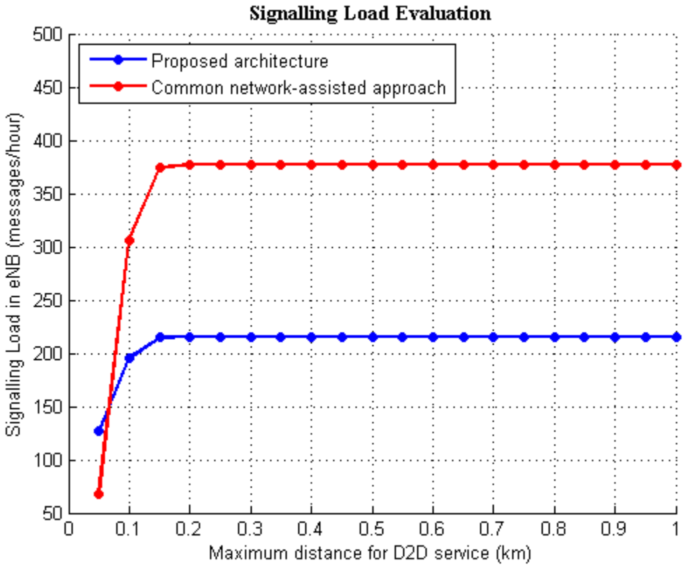

Fig. 10. Comparison of signaling load in an eNodeB with $P_{d2d} = 0.5$

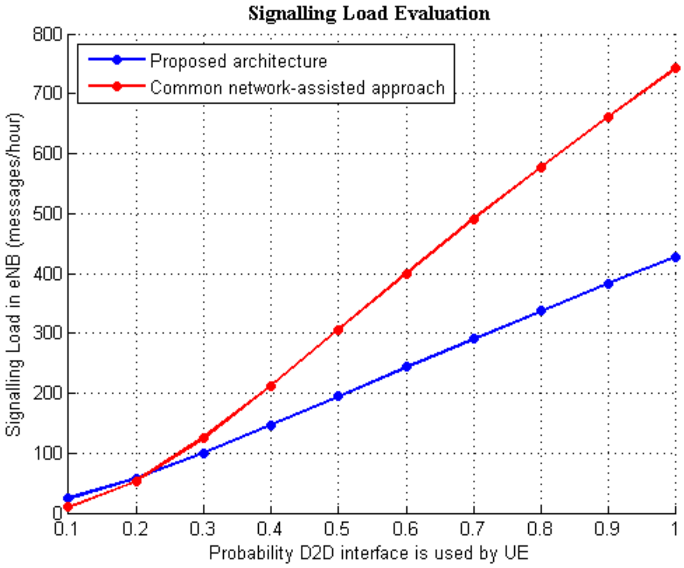

Fig. 11. Comparison of signaling load in an eNodeB with d = 100 m

3.3 Effect of Open vSwitch and local controller service on mobile device performance

Finally, we evaluate the effect of Open vSwitch and local controller service on mobile devices by a simple implementation. The test bed uses an Android mobile Nexus 5 running kernel 3.4.0.

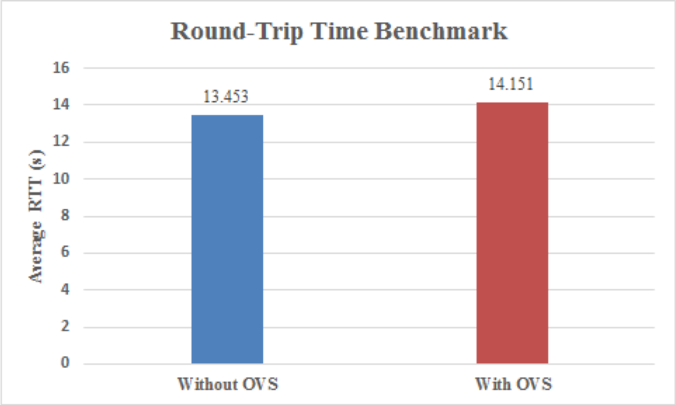

Fig. 12. Round-trip time benchmarking

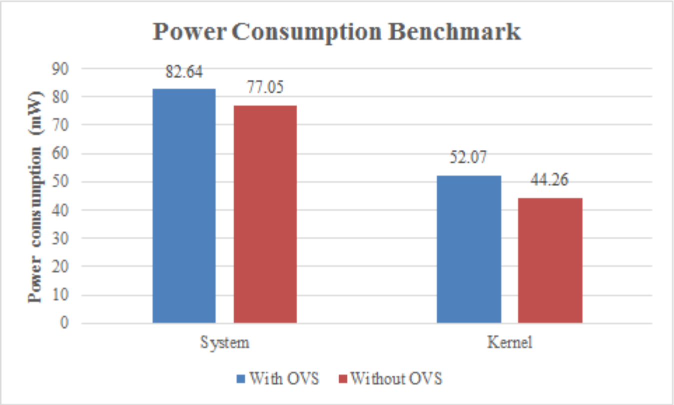

Fig. 13. Power consumption benchmarking

The version of Open vSwitch implemented is 1.11.0. We use the application PowerTutor to monitor the power consumption of the mobile device. The ping test shows that the average Round-Trip Time (RTT) increase 0.698(s) (~4.9%) is inconsiderable. The power consumption of System Services and Kernel increase by 6.7% and 12.76%, respectively, but this increase is also inconsiderable as the total energy consumption of an android mobile device is ~600mW. These results are described in **Fig. 12** and **Fig. 13**.

4. Conclusion

In this paper, we proposed an architecture that applies the SDN concept to D2D communication to allow establishment of a local network for proximity mobile users under full control of the cellular network. This proposed architecture brings numerous benefits, as mentioned above. In mathematic estimation, it reduces the energy requirement by ~50% compared with similar approaches that use Wi-fi direct for D2D communication. It also reduces signaling load in eNodeB in comparison with a typical network-assisted approach. By a simple implementation, we also found that the effect of Open vSwitch and the local controller service on mobile device performance is inconsiderable.

References

[1] A. Asadi, Q. Quang and V. Mancuso, “A Survey on Device-to-Device Communication in Cellular Networks,” *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 1801-1819, April, 2014. Article (CrossRef Link)

[2] D. Camps-Mur, A. Garcia-Saavedra, and P. Serrano, "Device-to-device communications with Wi-Fi Direct: overview and experimentation," *Wireless Communications*, vol. 20, no. 3, pp. 96-104, June, 2013. Article (CrossRef Link)

[3] G. Fodor et al., "Device-to-Device Communications for National Security and Public Safety," *IEEE Access*, vol. 2, pp. 1510-1520, 2014. Article (CrossRef Link)

[4] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Mikls and Z. Turnyi, "Design aspects of network assisted device-to-device communications," *IEEE Communications Magazine*, vol. 50, no. 3, pp. 170–177, 2012. Article (CrossRef Link)

[5] L. Lei, Z. Zhong, C. Lin, and X. Shen, "Operator controlled device-to-device communications in LTE-advanced networks," *IEEE Wireless Communications*, vol. 19, no. 3, pp. 96–104, 2012. Article (CrossRef Link)

[6] L. Lei et al., "Resource control in network assisted device-to-device communications: solutions and challenges," *IEEE Communications Magazine*, vol. 52, no. 6, pp. 108-117, 2014. Article (CrossRef Link)

[7] X. Lin, R. Ratasuk and A. Ghosh, "Network-Assisted Device-to-Device Scheduling in LTE," in *Proc. of Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st*, pp. 1-5, 2015. Article (CrossRef Link)

[8] S. Andreev, A. Pyattaev, K. Johnsson, O. Galinina and Y. Koucheryavy, "Cellular Traffic Offloading onto Network-Assisted Device-to-Device Connections," *IEEE Communications Magazine*, vol. 52, no. 4, pp. 20–31, April, 2014. Article (CrossRef Link)

[9] A. Pyattaev et al., "Network-assisted D2D communications: Implementing a technology prototype for cellular traffic offloading," in *Proc. of Wireless Communications and Networking Conference (WCNC), 2014 IEEE*, pp. 3266-3271, 2014. Article (CrossRef Link)

[10] M. Jo et al., "Device-to-device-based heterogeneous radio access network architecture for mobile cloud computing," *IEEE Wireless Communications*, vol. 22, no. 3, pp. 50–58, 2015. Article (CrossRef Link)

[11] S. H. Yeganeh and Y. Ganjali, "Kandoo: a framework for efficient and scalable offloading of control applications," in *Proc. of the first workshop on Hot topics in software defined networks*, pp. 19-24, 2012. Article (CrossRef Link)

[12] B. Pfaff, J. Pettit, K. Amidon, M. Casado, T. Koponen and S. Shenker, "Extending Networking into the Virtualization Layer," in *Hotnets*. 2009. Article (CrossRef Link)

[13] R. Riggio et al., "Programming software-defined wireless networks," in *Proc. of Network and Service Management (CNSM), 2014 10th International Conference on*, pp. 118-126, 2014. Article (CrossRef Link)

[14] Sang-Wook Kwon and D. Cho, "Efficient power management scheme considering inter-user QoS in wireless LAN," in *Proc. of Vehicular Technology Conference, 2006. VTC-2006 Fall. 2006 IEEE 64th*, pp. 1-5, 2006. Article (CrossRef Link)

[15] M. Yang et al., "Development of device-to-device communication in LTE-Advanced system," in *Proc. of Consumer Electronics (ICCE), 2014 IEEE International Conference on*, pp. 448-449, 2014. Article (CrossRef Link)

[16] I. Widjaja, P. Bosch, and H. L. Roche, "Comparison of mme signaling loads for long-term-evolution architectures," in *Proc. of Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*, pp. 1-5, 2009. Article (CrossRef Link)

[17] L. M. Feeney and M. Nilsson, "Investigating the Energy Consumption of a Wireless Network Interface in an AdHoc Networking Environment," in *Proc. of IEEE INFOCOM'2001*, vol.3, pp.1548-1557, April, 2001. Article (CrossRef Link)

Thanh-Hai Ngo received his B.S. degree in Electronics and Telecommunication Engineering from Hanoi University of Science and Technology, Vietnam, in 2009. He is currently pursuing M.S. degree in Information and Telecommunication Engineering from Soongsil University, Seoul, Korea. His research interests include Mobile Network Technologies, SDN (Software Defined Networking) and network function virtualization (NFV).

YoungHan Kim received his B. S. degree in electronics engineering from Seoul National University, Seoul, Korea, in 1984, and the M. S. and Ph. D. degrees in electrical engineering from Korea Advanced Institute of Science and Technology, Seoul, in 1986 and 1990 respectively. From 1987 to 1994 he was a senior member of the research staff in the Digicom Institute of Telemetics, Seoul, Korea, where he did research on data and computer communication systems. Since September 1994 he has been with Soongsil university, where he is a professor of school of electronic engineering. He is a director of Ubiquitous Network Research Center and a director of Convergence-ITRC (Convergence Information Technology Research Center) project supported by MSIP(Ministry of Science, ICT & Future Planning), Korea. His research interests include wireless networking and future networking, SDN (Software Defined Networking), ICN (Information Centric Networking) and sensor networking. He is a member of IEICE and IEEE.