DEVICE-TO-DEVICE-BASED HETEROGENEOUS RADIO ACCESS NETWORK ARCHITECTURE FOR MOBILE CLOUD COMPUTING

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ABSTRACT

The emerging heterogeneous mobile network architecture is designed for an increasing amount of traffic, quality requirements, and new mobile cloud computing demands. This article proposes a hierarchical cloud computing architecture to enhance performance by adding a mobile dynamic cloud formed by powerful mobile devices to a traditional general static cloud. A mobile dynamic cloud is based on heterogeneous wireless architecture where device-to-device communication is used for data transmission between user devices. The main advantage of the proposed architecture is an increase in overall capacity of a mobile network through improved channel utilization and traffic offloading from Long Term Evolution-Advanced to device-to-device communication links. Simulations show that the proposed architecture increases the capacity of a mobile network by up to 10 percent depending on the conditions and amount of offloaded data. The offloading probability is also evaluated by taking into consideration the number of devices in the cloudlet and the content matching values. We have gained insight into how content similarity affects offloading probability much more than the number of devices in a cloudlet.

INTRODUCTION

Internet service has penetrated deeply into our daily lives and is providing tremendous opportunities to simplify conventional tasks. A large volume of user data is stored in the cloud. The cloud provides ubiquitous access to personal information, data computing resources, and private enterprise systems for those connected to the Internet. The rapid increase in use of powerful mobile devices such as smartphones and tablets has made life quicker and more convenient. Mobile devices have become the most popular web access platform. Modern mobile devices are quite powerful and comparable to low-cost personal computers (PCs) in capacity. This has led to a new research field called mobile cloud computing.

Mobile cloud computing provides new types of services to mobile users, like bring your own device (BYOD), virtual credit cards, the Internet of Things (IoT), health care applications, interactive games, and even full high definition (HD) or 4K video streaming [1]. According to the Cisco Visual Networking Index forecast, mobile data traffic will reach 15.9 hexabytes per month by 2018. Therefore, many studies are being conducted to improve the performance of the overall cellular network by increasing spectrum and energy efficiency [2, 3], interference mitigation, and cooperative spectrum sharing [4]. Current cellular networks are unable to satisfy the rapidly growing spectrum requirements, despite the best efforts of researchers and technicians to improve network performance. This has led to the emergence of a completely new type of mobile network, the heterogeneous mobile network [5].

The main principle of heterogeneity is the coexistence of different types of communication protocols, services, and devices under a single network. A quality of experience (QoE)-based handover architecture for mobile heterogeneous networks (mobile HetNets) was proposed in 2013 [6]. This architecture extends the media-independent handover of IEEE 802.21 to QoE-aware seamless mobility, quality estimation, dynamic class of service mapping, and a set of content adaptation schemes. The advantages of HetNet convergence with device-to-device (D2D) underlay were assessed in terms of energy efficiency in [7]. The results suggest that the density of mobile subscribers, adopted backhaul solution, and spectrum resources that were used have a significant influence on cost saving benefits from cellular traffic offloading in HetNets. In general, the deployment of mobile HetNets gives us a significant gain in time to meet high user demands when there is a lack of spectrum resources. Sanaei *et al.* discussed the heterogeneity in convergent computing (both mobile and cloud computing) and networking (both wired and wireless networks) in 2014 [8]. They provided a mathematical description of multidimensional heterogeneity and illustrated code

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fragmentation problems that impede the development of cross-platform applications in mobile cloud computing. The impact of heterogeneity on mobile cloud computing was studied, and related opportunities and challenges were identified. An outline of new research directions like virtualization, middleware, and service-oriented architecture in mobile cloud computing was also presented [8].

In order to improve spectral efficiency and energy efficiency, and reduce capital and operational expenditures, a cloud radio access network (C-RAN) architecture was proposed [9]. In C-RAN architecture, a traditional cellular base station (BS) is decoupled into two entities: a baseband processing unit (BBU) and a remote radio head (RRH). The BBU provides all physical signal processing functionality, medium access control (MAC), and network layers including encoding, modulation, and so on. Modulated waveforms are transmitted from BBU to RRH via a fiber optic fronthaul. All BBUs are clustered together in one big data center (cloud) while RRHs are distributed in order to cover small target cells. C-RAN architecture provides high resource sharing flexibility, low-cost deployment, and convenient centralized network management. But C-RAN has disadvantages caused by cross-tier interference and fronthaul constraints, while HetNet has the disadvantages of low spectral efficiency due to a large amount of data signal and low energy efficiency in ultra-dense deployment. Peng *et al.* proposed heterogeneous C-RAN (H-CRAN) in 2014 to overcome the disadvantages of C-RAN and HetNets [10] by introducing the concept of shifting control and broadcast functionalities from RRHs to a macro BS. The proposed concept alleviates constraints due to capacity and time delay in fronthaul and allows the support of burst traffic transmission via RRHs. In H-CRAN, a BBU pool is interfaced with a macro BS to coordinate inter-tier interference between RRHs and macro BSs. RRHs only provide physical baseband processing functionality, while other procedures in upper layers are processed by the BBU pool [11].

This article proposes a concept of HetNet architecture that is different from H-CRAN in handling partial baseband functionalities. The proposed architecture focuses on shifting the computational load from a big cloud (called a general static cloud herein) to cloudlets (called mobile dynamic clouds in this article) consisting of powerful mobile devices that offer quick computing response for tasks generated by end-user devices like smartphones, laptop computers, and tablets. It definitely provides quick task processing in end-user devices without latency. Note that only end-user devices armed with a significant amount of better resources can be classified as powerful mobile devices capable of playing the role of masters and gateways in a cloudlet. We propose a new hierarchical heterogeneous architecture for D2D relay-based mobile cloudlets to reduce the latency and volume of data signaling between macro BSs and end-user devices. Our architecture assumes that mobile access points are based on D2D relay connections between mobile devices in close proximity.

Heterogeneous radio access network (HetRAN) architecture consists of two main parts, the general static cloud (GSC) and mobile dynamic cloud (MDC). The GSC is located in a fixed place. The capacity of a GSC is huge, and it is permanently reachable/accessible. The GSC is responsible for basic service models such as infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). This architecture is able to enhance the performance of H-CRAN by exploiting smartphone resources as mobile access points. All baseband functionalities on physical layers are shifted to mobile devices, while MAC and network layer functionality are distributed between MDC and GSC. The MDC is mobile and acts as an underlay to the GSC, which is responsible for offloading the partial traffic of existing general static clouds to mobile cloudlets. We assume that many end-user mobile devices in the MDC are capable of sharing their resources as members of a cloudlet. A cloudlet is a small cloud formed by mobile device resources. Offloading a portion of traffic to a cloudlet and distributing the BBU between the GSC and MDC improves load balancing, energy, spectrum efficiency, user experience, and the overall capacity and flexibility of a RAN.

The major contributions of this article are as follows:

1. The state-of-the-art models of mobile cloud computing and HetNets are examined.
2. A new HetRAN architecture for mobile cloud computing applications consisting of GSC and MDC parts is proposed.
3. The proposed HetRAN offers advantages of quick computing and reducing latency for tasks generated by end-user devices by borrowing resources from D2D communication-based mobile devices in a cloudlet instead of a big cloud.
4. The achievable transmission rates for different standards of D2D communications are analyzed.
5. A real network scenario of the proposed HetRAN is assessed, and the performance of the proposed approach is evaluated.

This article is organized as follows. We cover a comprehensive study of modern mobile cloud computing and HetRAN models. We describe the proposed architecture. We present a performance analysis and a case study with real-time scenario simulation. We conclude this article.

OVERVIEW OF THE EXISTING MOBILE CLOUD COMPUTING AND HETEROGENEOUS NETWORK MODELS

MOBILE CLOUD COMPUTING MODELS

The existing static cloud computing models are classified into three general service types: IaaS, PaaS, and SaaS. Differences lie in resource types and configuring opportunities offered to end users. The emerging mobile cloud computing introduces a new classification of service models that is based on roles and relationships between mobile service entities and fixed cloud service entities. Huang *et al.* outlined four types of mobile user collaboration in mobile cloud computing: mobile as a service consumer (MaaSC),

The most common model for current mobile cloud computing networks is MaaSC, in which mobile devices outsource their computation and storage resources to the cloud. This model is a simple developed version of the traditional client-server model with virtualization, fine-grained access control, and other basic cloud technologies.

MaaR represents each user as a virtualized entity in the cloud through a cellular network connection. User data collected from the environment in real time can be shared with other corresponding virtual entities, and it allows auxiliary data analysis and processing in the cloud.

mobile as a service provider (MaaSP), mobile as a service broker (MaaSB), and mobile as a service representer (MaaR) in 2013 [12].

The most common model for current mobile cloud computing networks is MaaSC, in which mobile devices outsource their computation and storage resources to the cloud. This model is a simple developed version of the traditional client-server model with virtualization, fine-grained access control, and other basic cloud technologies. Evolution in device computing and sensing capabilities has produced three types of mobile cloud computing models, MaaSP, MaaSB, and MaaR. In the MaaSP model, the mobile device is responsible for service provision. For example, mobile devices can collect data from the social and natural environment by using a large number of onboard sensors such as GPS, camera, and gyroscope, and share data with other mobile devices through the cloud. Also, the multimedia content stored in mobile devices can be shared between users if desired by the owners. In this case, consumers can simultaneously receive multiple data flows from the cloud and other devices. MaaSB is an extension of MaaSP, and provides networking and data forwarding services to other mobile devices. MaaSB can extend mobile cloud computing services to other devices by working as a gateway or proxy through a variety of air interfaces (wireless code-division multiple access [WCDMA], LTE-A, Wi-Fi, Bluetooth, etc.). MaaR represents each user as a virtualized entity in the cloud through a cellular network connection. User data collected from the environment in real time can be shared with other corresponding virtual entities, and allows auxiliary data analysis and processing in the cloud [12].

HETEROGENEOUS MOBILE NETWORK MODELS

A HetNet is a mobile network that combines different wireless access technologies, standards, and protocols. One HetNet model is D2D communication, and it functions as an underlay to a cellular network. D2D is a type of machine-to-machine (M2M) referred to only in communication between user equipment (UE) devices [13].

In D2D, user devices can communicate directly with each other without an eNB (BS). Currently, many D2D-based approaches have been designed for future HetNets. Modern devices can maintain separate connections simultaneously through different air interfaces like LTE/LTE-A, Wi-Fi, and Bluetooth. In certain scenarios, an eNB coordinates data transmission between user devices by providing them with necessary control information to support reliable D2D connection. Although the hardware is already capable for new D2D scenarios, the implementation of D2D in a current cellular network does not offer significant advantages to mobile cloud computing. At present, there are no existing protocols and standards for cooperation between eNBs and user devices for joint data processing as well as spectrum allocation.

The main limitation of D2D is the short distance required between two devices to support a reliable connection. Depending on the mobility of user devices, the distance between them varies. Therefore, there is a high probability for a D2D connection to fail when the distance between the user devices increases. As a result, new solutions are needed to overcome this problem in HetNets. A dynamic D2D network topology that allows control of reliable connections for high UE mobility scenarios, in a manner similar to sensor networks, might be a possible solution. Also, throughput and quality requirements in D2D communications are much higher than sensor networks. The existing protocol stack in mobile networks also needs improvement to support future HetNets.

HETEROGENEOUS RADIO ACCESS NETWORK FOR MOBILE CLOUD COMPUTING

GENERAL HETEROGENEOUS RAN ARCHITECTURE FOR MOBILE CLOUD COMPUTING

This section proposes a new architecture of a heterogeneous RAN for future applications. The MDC is created alongside an existing cloud, the GSC, to increase overall resource capacity and flexibility. The MDC is a combination of multiple cloudlets connected to each other through D2D communications under their master nodes. This paper proposes a hierarchical architecture where user devices have different roles in the cloudlet depending on its hardware performance. The GSC acts as the traditional static cloud and provides main service models, such as PaaS, IaaS and SaaS. The GSC is based on huge and powerful static data centers.

The static data centers are interconnected through extremely-high-throughput optical networks. This allows the GSC to maintain service provisions even when some data centers are unavailable. The quality of service (QoS) in mobile cloud computing depends significantly on the physical channel parameters, such as throughput and bit error probability. The physical channel parameters often vary because of user mobility, which leads to a decrease in QoS in mobile cloud computing. Moreover, data service access by many users from the GSC requires considerable spectrum resources, resulting in a decrease of overall network capacity. Therefore, the MDC is introduced to decrease traffic volume offloaded to the GSC. The MDC uses the computing resources of mobile devices (i.e., smartphones, tablets, and laptops), which contributes to network performance gain. Therefore, an MDC is created based on computing resources of user devices, with additional assistance from the GSC. In contrast to classic clouds, the resource capacity of MDCs does not remain constant for a long time because of the high mobility of user devices and limited range of D2D communication.

The computational performance of mobile devices is far lower than that of a static data center. Therefore, the assistance and support of the GSC is important to achieve better performance in mobile cloud computing. This article proposes the creation of cloudlets from mobile devices in order to borrow their computational capabilities. The cloudlet will perform simple computational tasks, thereby reducing the load of the GSC. This also allows the elimination of a large quan-

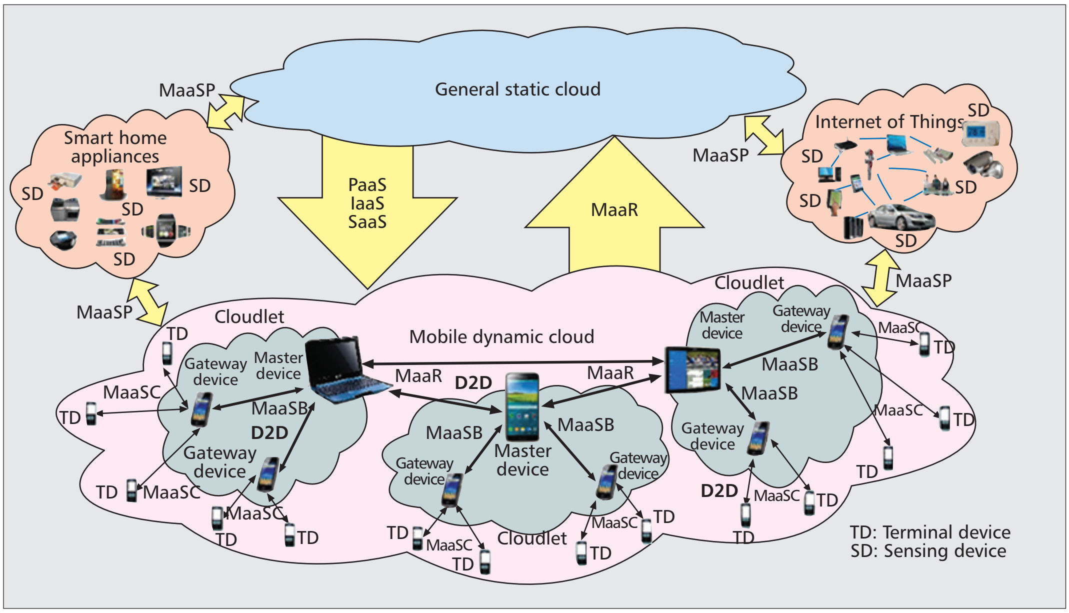

Figure 1. D2D-based HetNet architecture for mobile cloud computing. All devices inside the MDC communicate by D2D communication technology.

This article proposes a hierarchical architecture where user devices have different roles in the cloudlet depending on its hardware performance. The GSC acts as the traditional static cloud and provides main service models, such as PaaS, IaaS, and SaaS. GSC is based on huge and powerful static data centers.

tity of data transmission from mobile devices to the GSC, and prevents the release of a wide band of spectrum. Figure 1 shows the proposed D2D-based mobile HetNets architecture.

This article suggests four different modes of mobile device operation based on a familiar mobile cloud computing model that is discussed in the previous section [12]. The first mode is terminal device (TD), which can only perform in a MaaSC model. All user devices with low computing resources (i.e., economy-class mobile devices) operate in TD mode. Normally, devices in TD mode can neither share their computational and storage resources nor perform complex tasks without external assistance. TDs need external assistance, like additional CPU or memory resources, if they want to share their own resources.

The second mode is the gateway device (GD) mode that relates to mobile devices as a service broker model. A GD can forward necessary data from TDs to master devices (MDs) and vice versa. As shown in Fig. 1, in an uplink channel, a GD forwards the data of several terminal devices to the corresponding MD. In a downlink, the GD forwards data from a master device to terminal devices. The third mode is sensing device (SD) mode with unique sensing capabilities. These devices cannot provide any computational resources and work outside of the MDC and GDS, as shown in Fig. 1. This mode functions as a service provider model, and the SD provides sensed data to all mobile cloud computing users by utilizing their own sensing capabilities. These devices can be programmed to specialize in a single task (e.g., climate control sensor, closed-circuit television camera, car video recording device, healthcare device, and smart home appliances). Or they can be programmed for a combination of tasks with other mobile devices with GPS, cameras, thermo sensors, heart rate sensors, wireless spectrum sensors, and so on.

The number of sensing devices has been growing rapidly due to the emerging IoT. IoT brings a lot of smart devices that communicate among themselves and interact with the GSC and MDC. One good example of the application of IoT is a healthcare service with wearable sensing devices connected to the cloud [14]. Healthcare applications often use cloud computing to conduct complicated data processing. Personal devices such as smartphones, tablets, and laptop computers can also process a portion of healthcare tasks in a cloudlet in the proposed architecture. We assume that in the proposed architecture, IoT devices are connected to the general static cloud, through either fixed access points or mobile devices.

The fourth mode is MD mode, and it is responsible for the mobile device to operate as a service representer. Such a device normally has very powerful hardware (e.g., 4 or more CPU cores, at least 3 GB RAM, and almost all possible air interfaces) and advanced software (the latest version of Android, Tizen, IOS, MS Windows, etc.). The master device can be a powerful smartphone, tablet, or laptop (if these master devices support enough air interfaces), as shown in Fig. 1. In service representer mode, the MDs normally perform many tasks that are transferred from other devices, provide direct high-throughput communications to the GSC, and represent all young devices as virtual entities in the cloud. The MDs communicate through D2D communication to combine their performance. The MDC is created by collaborating with all different types of devices in different operating modes. The performance of a cloudlet is limited by an MD, which in turn can provide access to a limited number of GDs. The performance of a GD is also limited due to a few TDs. Therefore, total cloudlet performance is limited by two parameters: the number of GDs and number of TDs. The two parameters determine maximal cloudlet size.

Note that in our proposed architecture, all mobile devices in the network still keep an option for conventional direct communication with GSC through a cellular BS if a D2D connection is weak or unavailable. Moreover, in this article we have not considered a complicated scenario in which some mobile devices are connected through D2D communication while some are connected through direct cellular communication.

INTERACTION BETWEEN USER DEVICES IN HETEROGENEOUS MOBILE NETWORKS

The proposed D2D-based mobile HetNet architecture assumes five different scenarios for a wireless connection (TD-GD, GD-GD, GD-MD, MD-MD, and MD-GSC), which are classified according to the type of communicating device. Note that user devices may operate in different modes depending on minimal hardware requirements. For example, high-capacity devices can operate as a master, gateway, or terminal device. However, low-capacity devices cannot operate as gateway or master device due to a lack of resources. Table 1 lists the classification of the suggested communication scenarios.

The communication scenario in MDC is classified according to the following criteria:

- Wireless communication standard, such as Wi-Fi, Bluetooth, LTE
- Mobile cloud computing model, such as MaaSC, MaaSB, MaaSP, MaaR
- Minimal hardware requirements of devices (i.e. CPU, RAM, air interface)
- Communication domain (cloudlet, MDC, GSC)

For example, the TD-GD communication scenario is limited to TD communication capabilities. The TD can communicate with GD through Wi-Fi or Bluetooth standards. In this

Criteria Scenario	Wireless communication standard	Mobile cloud computing model	Communication domain	Minimal requirements for devices	Tasks
TD-GD	D2D: Bluetooth 4.0/Wi-Fi 802.11g/n	TD: MaaSC GD: MaaSB	Cloudlet	**TD:** BT 4.0, 802.11g/n; **GD:** BT 4.0, 802.11g/n, 2 GHz CPU, 2 Gb RAM	The TD is connected to the global network through the GD, and sometimes outsources its own complex computational tasks for the MD.
GD-GD	D2D: Bluetooth 4.0/Wi-Fi 802.11 g/n/ac	MaaSB	Cloudlet	BT 4.0, 802.11g/n, 2 GHz CPU, 2 Gb RAM;	Bridge connection between two GDs for data forwarding if the MD is unreachable for the first GD.
GD-MD	D2D: Bluetooth 4.0/Wi-Fi 802.11 g/n/ac	GD: MaaSB MD:MaaSP	Cloudlet	**GD:** BT 4.0, 802.11 g/n, 2 GHz CPU, 2 Gb RAM; **MD:** LTE, BT 4.0, 802.11g/n, 3 GHz CPU, 3 Gb RAM;	The GD transmits both its own and the data for all the TDs to the MD. The MD computes the low complicated data, and returns it to cloudlet users by utilizing separate virtual machines for each TD.
MD-MD	D2D: Bluetooth 4.0/Wi-Fi 802.11 g/n/ac	MaaSP/MaaSB	MDC	LTE, BT 4.0, 802.11 g/n, 3 GHz CPU, 3 Gb RAM;	The MDs collaborate among themselves to create a more powerful MDC and exchange necessary data by virtual machines migration to provide soft handover if the user moves from one cloudlet area to another.
MD-GSC	Cellular: LTE/LTE-AHSPA+/WiMAX 802.16eWi-Fi 802.11 ac	MaaR	GSC	**MD:** LTE, BT 4.0, 802.11 g/n/ac, 3 GHz CPU,3 Gb RAM; **GSC:** relatively unlimited	The MD represents the entire network as virtual entities in a GSC. All complex data, which cannot be processed by an MDC, is outsourced to the GSC. The GSC provides all network services to the users through the MD and cellular connection.
SD-GSC	D2D: Bluetooth 4.0/Wi-Fi 802.11 g/n/ac	MaaR	GSC	**SD:** 802.11 g/n/ac, sensing capabilities **GSC:** relatively unlimited	The SD provides public data acquisition services such as smart city control, environmental monitoring, CCTV camera, and public transportation.
SD-MDC	D2D: Bluetooth 4.0/Wi-Fi 802.11 g/n/ac	MaaR	MSC	**SD:** 802.11 g/n/ac, sensing capabilities **MDC:** BT 4.0, 802.11g/n;	The SD provides personal data acquisition services such as smart home appliances, car control systems, and healthcare services.

Table 1. Types of connection scenarios within the mobile dynamic cloud.

scenario, the TD supports the MaaSC model, while the GD supports the MaaSB model, as shown in Table 1. The GD has higher requirements for minimal hardware for data forwarding from TD to MD and vice versa. The other scenarios described in Table 1 function in the same manner.

DATA TRANSMISSION AND INTERACTION IN MOBILE CLOUD HETNETS

Implementation of the proposed D2D-based HetNet architecture requires completely new traffic management policies and new algorithms for joint data processing. In this proposed HetNet mobile cloud computing architecture, the mobile devices are independent of each other and maintain separate connections with the main general static cloud, which is different from traditional mobile cloud computing. In heterogeneous architecture, sequential data aggregation is used by at least three hops. First, the GD collects and processes the data from all the connected TDs. The collected data is sent to the MD. Note that the GD does not calculate any data except for its own, and so all the data received from the TDs should be forwarded to another GD or the nearest MD for computing. If the second GD receives data from the first GD, it aggregates them together with its young TDs and then transmits them to the MD. Finally, the MD receives all data from its cloudlet and processes it according to service type and computing capability.

If the MD decides that some tasks are too complicated or require a higher computing resource capacity, it aggregates all data and forwards it to GSC. The MD calculates all simple tasks obtained from the GD simultaneously, and sends them back to the GD via D2D communications. On the other hand, GSC processes all the data from the MDs and sends them back to the requesters. Figure 2 shows the data transmission diagram for HetNets.

As shown in Fig. 2, the data is classified into three types: a single user's data from the TD, multiple users' data from the GD, and cloudlet data from the MD.

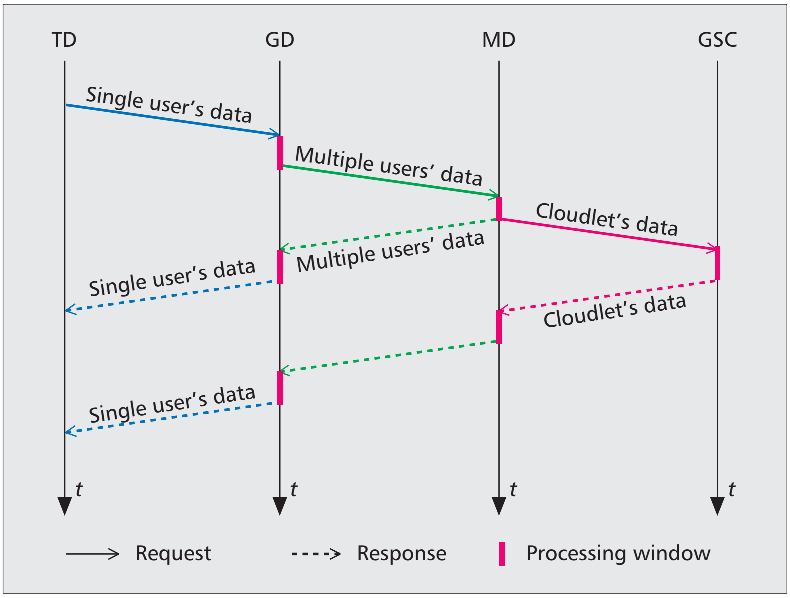

Figure 2. Data transmission diagram in the proposed D2D-based HetNet architecture for mobile cloud computing.

PERFORMANCE ANALYSIS OF PROPOSED HETNET FOR MOBILE CLOUD COMPUTING

ACHIEVABLE TRANSMISSION RATES OF DIFFERENT WIRELESS STANDARDS IN MOBILE HETNETS

In our research, the D2D communications in heterogeneous networks use two different network protocols, Wi-Fi Direct and Bluetooth 4.0. According to the Bluetooth 4.0 standard, the capacity of the Bluetooth D2D channel is equal to 24 Mb/s in a spectrum range of 2402–2480 MHz. The capacity of a Wi-Fi channel is equal to 150 Mb/s, which allows the connection of many more users compared to Bluetooth. On the other hand, increasing the number of connected devices enormously decreases the throughput per user because of the use of the carrier sense multiple access with collision avoidance (CSMA/CA) technique, which requires a large number of retransmissions when collisions occur. Therefore, performance of the two standards considered here are similar in a real wireless environment and for relatively small distances. In our research, the LTE-A Release (Rel) 10 standard for communications is used between the master devices and GSC. LTE-A offers tremendous capacity equal to 1.5 Gb/s and 3 Gb/s for uplink and downlink channels, respectively. This allows for the transmission of a large amount of data in real time between the GSC and MDC.

EVALUATION OF THE PROPOSED D2D-BASED HETNET ARCHITECTURE

The efficiency of an LTE-A network impacts mobile cloud computing performance significantly. The main aim of the proposed D2D-based HetNet architecture is to increase the overall spectral efficiency by reducing the number of transmissions between the BS (eNB) in GSC and user devices. To achieve higher spectral efficiency in the proposed HetNet, the widest possible spectrum bands were allocated for several master nodes. To evaluate the performance of the proposed D2D-based HetNet mobile cloud computing architecture, the HetNet simulation model was built in the LTE System Toolbox of Matlab R2014b. The simulation of the data transmission process was performed with a random number of simultaneous mobile cloud service access users. For simplification, the following parameters are defined for the simulation:

- Bandwidth: 20 MHz
- Modulation: 64-QAM
- Antenna configuration: omnidirectional
- MD-GD transmission: Wi-Fi Direct up to 5 Mb/s
- GD-TD/SD-GD transmission: Bluetooth 4.0 up to 1 Mb/s

- Maximum number of GDs that can be connected to MD: 5
- Maximum number of TDs/SDs that can be connected to a GD: 5
- Users' location distribution: uniform
- Users' traffic distribution: Poisson
- IoT traffic distribution: uniform

Network Capacity Performance Analysis — The instantaneous network capacity was simulated under random conditions over a one-hour period for four different scenarios: eNB capacity for an ordinary LTE-A network, eNB capacity for the proposed D2D-based HetNet architecture without traffic offloading from GSC to MDC, total capacity of HetNet with traffic offloading from GSC to MDC, and total capacity of HetNet with IoT, respectively. As shown in Fig. 3, the experimental results show that eNB capacity of ordinary network architecture without D2D-based HetNet is unstable and depends on the number of users. On the other hand, the proposed D2D-based HetNet mobile cloud architecture showed more stable network performance regardless of the number of users, and the capacity increases by 5 percent when the D2D-based HetNet does not allow for traffic offloading from GDC to MDC, compared to the ordinary LTE-A network. A similar curve is observed for HetNet with IoT, but with higher capacity values. HetNet without offloading and HetNet with IoT curves are similar, because IoT traffic is nearly constant due to continuous low energy data transmission from IoT devices. If traffic is allowed to be offloaded from GSC to MDC, their capacity increases up to 10 percent in our simulation scenario when compared with an ordinary LTE-A network, as shown in Fig. 3.

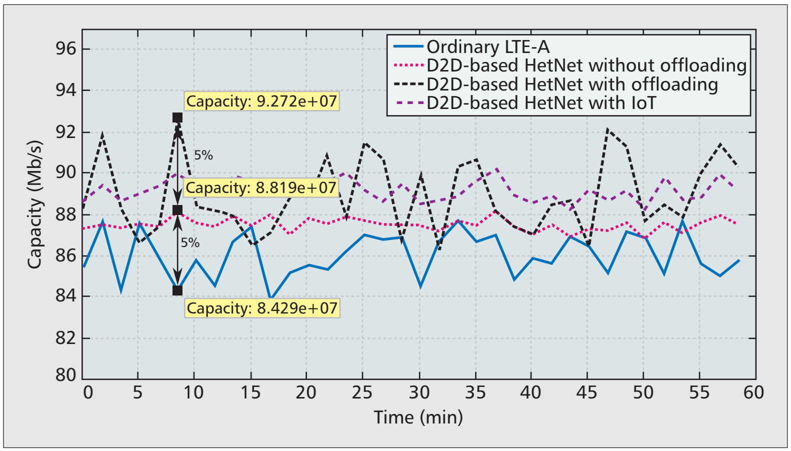

Figure 3. Network capacity comparison of different scenarios for one cell.

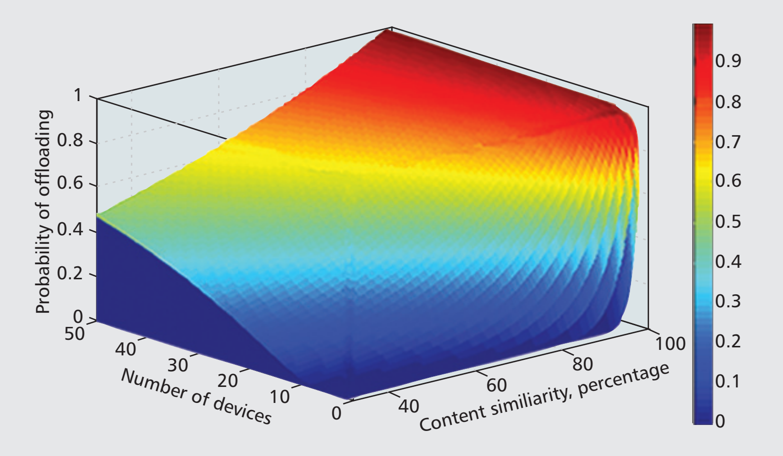

Figure 4. Three-dimensional relationship plot of offloading probability.

The advantage was gained by using three steps of data transmission from the TD to the GSC, as shown in Fig. 2. First, the GD collects data from multiple TDs and aggregates it into a single data flow. Second, the GDs transmit the aggregated data flow to the MD. The MD collects all the data from multiple GDs into a single aggregated data flow and transmits it to GSC through eNB. This approach increases the utilization of eNB resources by decreasing the total number of requests from the MDC to eNB, as shown in the eNB capacity with HetNet plot in Fig. 3.

In ordinary LTE air interface, a lot of signaling data is transmitted to maintain a stable connection for each user. Signaling data is transmitted via specified control channels such as physical control format indicator channel (PCFICH), physical hybrid ARQ indicator channel (PHICH), physical downlink control channel (PDCCH), reference signal (RS), and primary (secondary)-synchronization signal (P(S)-SS) [14]. The total amount of signaling data depends on the number of simultaneous transmission sessions. Therefore, our approach provides an advantage by increasing capacity and reducing the number of simultaneous transmissions from the base station even without traffic offloading to mobile clouds, as shown in Fig. 3. In addition, offloading allows a sufficient increase in network capacity when some part of data processing is done inside the MDC without transmission to the GSC. In this case, traffic is kept inside the MDC without using base station resources, which definitely leads to an increase in capacity as shown by the total eNB and HetNet capacity plot in Fig. 3.

Offloading Probability Analysis — The capacity is affected by the amount of data offloading from eNB in GSC to MDC. The advantage of traffic offloading from eNB in GSC to MDC will be outstanding for some case with high traffic density areas and similar user demands, such as airports, railway stations, and sport stadiums. A probabilistic simulation by Matlab was used to figure out how network circumstances affect offloading probability. The probability of service traffic offloading from the GSC to the MDC was calculated to measure content similarity and number of devices within the cloudlet. The increasing number of mobile devices causes an increased probability of connections among them. In addition, the offloading probability will be higher when the similarity of service contents increases. Figure 4 shows the three-dimensional relationship of the offloading probability with the content similarity value and the number of devices.

According to the experimental results in Fig. 4, the probability of offloading from the eNB in the GSC to the MDC is proportional to the percentage of content similarity. If the number of devices increases, in addition to the increasing percentage of content similarity, the probability of offloading would increase more drastically. The results provide insight in that both factors, rather than a single factor, significantly influenced the probability of offloading.

Further insight was gained from the experimental results in which, from the point of more than 80 percent content similarity, the probability of offloading begins to increase dramatically, regardless of a high or low number of devices. When the content similarity is lower than 50, the probability of offloading does not change significantly, even though the number of devices increases greatly. Overall, the level of content similarity affects the frequency of offloading from eNB in GSC to MDC much more than the number of devices in a cloudlet. Figure 5 shows how the offloading probability depends on the number of users for three different types of services: web services, cloud services, and multimedia services.

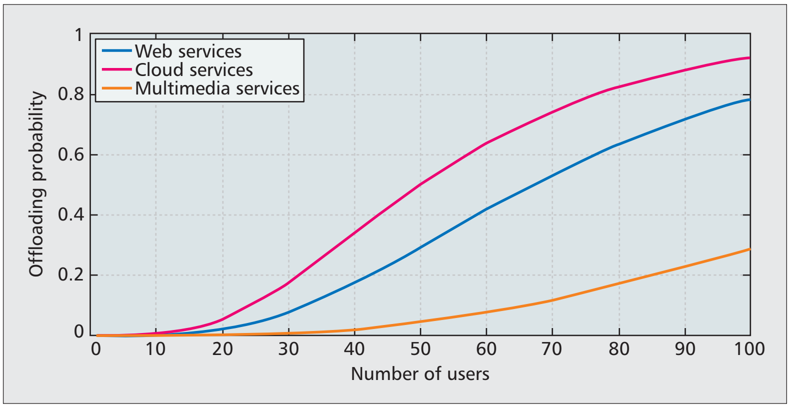

Figure 5. Offloading probability vs. number of users for different types of services.

As shown in Fig. 5, cloud services have the highest offloading probability, which results from context-aware cloud computing. It is very probable that users within the D2D communication area use the same cloud services (weather forecast system, public transportation system, etc.). Web services also have high offloading probability, because it is very possible for many users to access the same information resources such as local area news and city web portals. The lowest offloading probability is for multimedia services such as YouTube and others. Even though many users request the same multimedia content, offloading probability is still low, because the same videos or songs may be stored under different file names. This complicates the detection of similar multimedia content that can be offloaded from one device to another.

CONCLUSION

A HetNet mobile cloud computing architecture that is different from traditional static cloud computing and existing mobile cloud computing was proposed. The new architecture consists of two layers, a GSC and an MDC. The proposed architecture utilizes the advantages of D2D communications utilizing both heterogeneous networks, Wi-Fi, and Bluetooth in the cloudlet. The performance of the HetNet capacity with and without traffic offloading to MDC was measured. We have found that when traffic offloading from GSC to MDC is allowed, the network capacity automatically increases. The probability of offloading with HetNet under two parameters, content similarity and number of users, was also assessed. The level of content similarity was found to affect the frequency of offloading much more than the number of users in the cloud. Future research will examine how the proposed architecture affects the resource availability of eNB in the GSC.

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