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Cloudlet-based Efficient Data Collection in Wireless Body Area Networks

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ABSTRACT

Wireless Body Area Networks (WBANs) have developed as an effective solution for a wide range of healthcare, military and sports applications. Most of the proposed works studied efficient data collection from individual and traditional WBANs. Cloud computing is a new computing model that is continuously evolving and spreading. This paper presents a novel cloudlet-based efficient data collection system in WBANs. The goal is to have a large scale of monitored data of WBANs to be available at the end user or to the service provider in reliable manner. A prototype of WBANs, including Virtual Machine (VM) and Virtualized Cloudlet (VC) has been proposed for simulation characterizing efficient data collection in WBANs. Using the prototype system, we provide a scalable storage and processing infrastructure for large scale WBANs system. This infrastructure will be efficiently able to handle the large size of data generated by the WBANs system, by storing these data and performing analysis operations on it. The proposed model is fully supporting for WBANs system mobility using cost effective communication technologies of WiFi and cellular which are supported by WBANs and VC systems. This is in contrast of many of available mHealth solutions that is limited for high cost communication technology, such as 3G and LTE. Performance of the proposed prototype is evaluated via an extended version of CloudSim simulator. It is shown that the average power consumption and delay of the collected data is tremendously decreased by increasing the number of VMs and VCs.

1. Introduction

1.1. Wireless body area networks

Wireless Body Area Networks (WBAN) comprises of a group of communicating sensor nodes. These sensor nodes can be implanted or wearable, which can monitor different vital body parameters and gather a lot of body information [1–5]. These devices, communicating through wireless technologies, can transmit data from the body to a home base station from where the data can be forwarded to a hospital, clinic, or a service provider in real-time manner. The WBAN technology is still in its primitive stage and is being widely researched. The technology, once accepted and adopted, is expected to be a breakthrough invention in many healthcare applications, leading to concepts like telemedicine and mobile health monitoring.

Initial applications of WBANs are expected to appear primarily in the healthcare domain, especially for continuous monitoring and logging vital parameters of patients suffering from chronic diseases such as diabetes, asthma and heart attacks, as

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well as in elder care monitoring. Other emerging applications of this technology include military, sports, gaming, social computing, entertainment and security. Extending the technology to new areas could also assist communication by seamless exchanges of information between individuals, or between individual and machines.

Wearable system in the real-time health monitoring is the most important skill in moving to more efficient and proactive health service. These systems permit persons to monitor the changes in their own vital signs. Then, these systems send responses to the service provider to maintain a standard healthiness position. On the other hand, a telemedical system can be integrated with the wearable systems to provide watchful health recruits when there is a change in the life-threatening. Furthermore, the proposed systems can be used for health monitoring of patients in ambulatory settings [6]. For example, they can be used as a part of a analytic technique, optimal maintenance of a chronic condition, a supervised recovery from an acute event or surgical procedure, to monitor adherence to treatment guidelines (e.g., regular cardiovascular exercise), or to monitor effects of drug therapy.

The multiple WBAN sensor nodes are capable of sampling, processing, and communicating one or more vital signs like heart rate, blood pressure, oxygen saturation, breathing rate, diabetes, body temperature, ECG and activity, or environmental parameters like location, temperature, humidity, light, movement, proximity and direction. Typically, these sensors are implanted or placed strategically on the human body as tiny patches or hidden in users' clothes allowing ubiquitous health monitoring in their native environment for extended periods of time.

1.2. Cloud computing

Cloud computing is a new computing paradigm that is continuously evolving and spreading. Empowered by hardware virtualization technology, parallel computing, distributed computing, and web services, cloud computing present a huge revolution in the information and communication technology [8]. Cloud computing can be defined as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [9]. There are several examples for emerging cloud computing infrastructures and platforms such as Microsoft Azure [9], Amazon EC2, Google App Engine, and other on premises cloud, i.e. private cloud [10]. Furthermore, cloud computing helps companies to improve the IT services, development of applications to achieve unlimited scalability, automaticity on demand services of the IT infrastructure, and increasing their revenues [11]. Cloud Computing service models include: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Clients of cloud computing might be users in other Clouds, organizations, enterprises, or might be a single user [8].

1.3. Cloudlet and wireless body area networks

The huge amount of data collected by WBAN nodes demands scalable, on-demand, powerful, and secure storage and processing infrastructure. Cloud computing is playing a significant role in achieving the aforementioned objectives. The cloud computing environment links different devices ranging from miniaturized sensor nodes to high-performance supercomputers for delivering people-centric and context-centric services to the individuals and industries. The possible integration of WBANs with cloud computing will introduce viable and hybrid platform that must be able to process the huge amount of data collected from multiple WBANs. This WBAN-cloud model will enable end users to globally access the processing and storage infrastructure at economical costs. On the other hand, since WBANs forward useful and life-critical information to the cloud, which may operate in distributed and hostile environments, novel security mechanisms are required to prevent malicious interactions to the storage infrastructure. Both the cloud providers and the users must take strong security measures to protect the storage infrastructure.

A cloudlet is a new architectural element that arises from the convergence of mobile computing and cloud computing. It represents the middle level of a 3-level hierarchy; WBAN, cloudlet and cloud. A cloudlet can be viewed as a data center in a box whose goal is to bring the cloud capabilities closer to the users. This paper discuses a novel model that exploit cloudlet based computing for supporting large scale data collection in WBANs. The model brings a high computing capacity of cloud system closer to the WBANs users. This will help WBANs users to be connected directly to cloud resources using cheaper communication technologies.

1.4. Objectives and contributions

The main goal of this paper is to develop a large scale WBANs system in the presence of cloudlet-based data collection model. The objective is to minimize end-to-end packet cost by dynamically choosing data collection to the cloud by using cloudlet based system. The goal is to have a large monitored data of WBANs to be available to the end user or to the service provider in reliable manner. While reducing packet-to-cloud energy, the proposed work also attempt to minimize the end-to-end packet delay by choosing cloudlet so that the overall delay is minimized, thus leading to have the monitored data in the cloud in real time mode. Note that in the absence of network congestions in low data-rate WBANs, the storage delays due to data collection manner are usually much larger compared to the congestion delay.

Specific contributions of the paper are as follows. First, we develop a prototype body area network system for motivating the on-body packet data collection to the cloud and validating the proposed system. Second, using the prototype network, we provide a scalable storage and processing infrastructure for large scale WBANs system. This infrastructure will be efficiently able to handle the large size of data generated by the WBANs system by storing these data and performing analysis operations on it. Third, a cloudlet-based data collection is fully supporting for WBANs system mobility using cost effective communication technologies that are supported by both the WBANs system and the cloudlet system. This is in contrast of many of available mHealth solutions that is limited for high cost communication technology such as 3G and LTE. Fourth, the proposed model introduces a reliable and fault tolerance solution that is able to handle WBANs system load with different usage scenario and with different scale. Fifth, the proposed solution is universal and can be deployed in a large scale environment with different usage scenarios, such as firefighters, military, students in school or university or elders in *elderly house*. Sixth, the cost effective of the proposed solution does not need special equipment in WBANs side nor in cloudlet side. Finally, the performance of the proposed model is experimentally evaluated using CloudSim simulator to see the impact of the number of the Virtualized Cloudlets and the deployment locations on the results.

2. Related work

On-body data communication can be multi-point-to-point or point-to-point which depends on the target application. Applications such as monitoring vital signs of a patient will require all implanted and body-mounted sensors to transmit data to a sink node, which in turn will relay the information wirelessly to an out-of-body server.

The advantage of center-based data collection approaches is coming from the combining of the data packets from multiple nodes in order to reduce the network energy [7]. Combining multiple packets process to form one single packet is called data collection [12]. The idea of data collection is to reduce the number of packets that are transmitted through the network. Then, the overall energy is reduced. The data collection prototypes introduced in [13–15] are using energy efficient approach by combining multiple packets received from multiple nodes and forwarding a single packet to the destination. In these prototypes, multiple sensor nodes observe same event. Similarly, the midway nodes observe same event and aggregate the data to a single forwarding packet. These prototypes are not fit in WBAN prototype because the following. First, the data observations of the sensor nodes in a WBAN are complimentary in order to make any conclusion [16]. Second, in wireless sensor networks the goal of data collection is to reduce the number of packet communications by removing redundancy in the data [17]. Nevertheless, the objective of this paper is to reduce packet transmission energy by using Wi-Fi comparing with cellular communication. Comparing with multiple transmissions in wireless sensor networks, sensor nodes in WBAN are designed for direct transmissions. However, the huge amount of data collected by WBAN nodes demands scalable and powerful data transmission, storage and processing infrastructure. Cloudlet-based data collection proposed in this paper is playing a significant role in achieving the aforementioned objectives. To the best of our knowledge, such study has not been done previously.

The usage of WBAN for health monitoring received a great attention for more than a decade. The authors in [18] introduced mHealth technique which is a WBAN based technique that provides a viable solution for unobtrusive daily patient health monitoring. However, the paper uses the stander mHealth concept for data collection and communication while using cloud computing only for data storage and processing in the enterprise level [18]. A service-oriented based middleware (SOA) for WBAN has been presented in [19]. The proposed architecture assumes that WBAN sensors are able to transmit data using a gateway node, which is responsible about retransmitting of the data to a remote computing unit. Also, the gate way node is able to receive control information and other queries to the WBAN from a remote node.

The author in [20] proposed MobiCloud, which describes how the mobile cloud computing is developed from cloud computing and mobile computing. In this study, the author develops the scope of the MobiCloud. Then, he studied the current research challenges of mobile cloud computing. The proposed MobiCloud system is developed to simplify the studying and analyzing the mobile cloud computing. The impact of using Cloudlet with respect to cloud mobile computing in interactive applications (file editing, video streaming and collaborative chatting) is analyzed in [21]. The proposed work compared two models in terms of system throughput and data transfer delay. The paper results showed that in most cases the use of cloudlet-based model outperformed the cloud-based model. The authors in [22] proposed new architecture called MOCHA for face recognition applications. The aim of the purpose architecture is to reduce the response time during face recognition process. MOCHA integrates Mobile device, cloudlet and cloud servers. Admission control and resource allocation problems for the running mobile application in the cloudlet have been studied in [23]. The authors in this paper solve these problems by formulating them as a Semi-Markov Decision Process (SMDP). The proposed model in this paper provides a QoS for different classes of mobile users. Technical obstacles of using cloudlet in mobile computing have been studied in [24]. A new architecture has been proposed to deal with the studied obstacles. The proposed architecture manages the sessions opened by mobile users inside the cloudlet. The management is conducted based on virtual machine instantiations for each mobile user.

The novelty of the integration between WBANs system and cloud computing came from the ability of cloud system to support the continually increasing and incredibly demands on WBANs as scalable storage and high capacity computing resources. To the best of our knowledge, the novelty of the proposed work has never been addressed in any previous studies. Moreover, mobility-aware solutions were never proposed on a large scale as it's fully supported by our proposed cloudlet-based WBANs system. While most of the previous proposed solutions were mainly targeting health related issues, our proposed solution provide a holistic solution that can be deployed in different environments which are not limited in the health

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care systems. Examples of these applications are firefighters, military, students in school or university or elders in elderly house, where the deployment of the cloudlets depends on the mobility and clustering the users in these applications.

3. Preliminary exploration

3.1. WBAN system prototype

A *Wireless* Body Area Network (*WBAN*) is constructed by mounting several sensor nodes on a human subject. the sensor node are used for collecting different modalities, like, blood pressure, heart rate, breathing rate, diabetes, temperature, humidity, ECG, movement, proximity, direction, etc. The sensor node can be mounted on the arms, head, thighs, wrist, ankles and the waist space, Fig. 1 summarizes the possible mounted placers. The wearable sensor node consists of a 900 MHz Mica2Dot MOTE with Chipcon's SmartRF CC1000 radio chip (chipcon.com), and the sensor card MTS510 from Crossbow Inc. (xbow.com). The Mica2Dot mote is running TinyOS operating system to collect different sensing modalities. 570 mAH button cell battery is used to run the Mica2Dot nodes with a total sensor weight of approximately 10 g. The default Carrier Sense Multiple Access (CSMA) Media Access Control (MAC) protocol is used with a data rate of 19.2 kbps. In order to save more power and having long running system, via software adjustments of the CC1000's transmission power, the transmission range is set to be no longer than 1 m. In addition, having low transmission power, we are able to avoid any interferences between different WBANs in the network and we are able to emulate ultra-low transmission range for the embedded transceivers [25–27]. The sensors form a star topology, where each sensor sends its sensing modalities data to the sink node, at which; the collected data can be aggregated in one data packet. The aggregated data packet is then sent via Bluetooth to a smart phone or a Personal Digital Assistant (PDA) for WBAN monitoring application. A web-service module is then used to upload the observed data to the server using either WiFi or cellular data communication.

WiFi is a popular technology that allows an electronic device to exchange data or connect to the internet wirelessly using radio waves. It is defined as Wireless Local Area Network (WLAN) product which is based on IEEE 802.11 standards [28]. While cellular network is a radio network distributed over areas, each served by at least one fixed-location transceiver. A cellular network enables large number of mobile phones to communicate with each other and with fixed transceivers of Internet. The trades between using these two technologies are the followings. With WiFi, a WBAN user will be able to transmit the data packet to the cloud with low power and low delay compared with cellular technology [29], but with transmission range does not exceed 100 m [30]. Such WiFi capability is crucial to support the power constrained in WBAN sensors while successfully transmitting data to the cloud system. In our implementation, the WiFi technology will be available in the cloudlet area. It was shown that, via WiFi, the transmission power of a data packet of size 46 Bytes will cost about 30 mw [29,31,32] and with a delay of 0.045 ms. On the other hand, a longer transmission range cellular network connection (e.g. 3G and LTE) is capable of transmitting the data packet to the cloud from any location that is cover by cellular network,

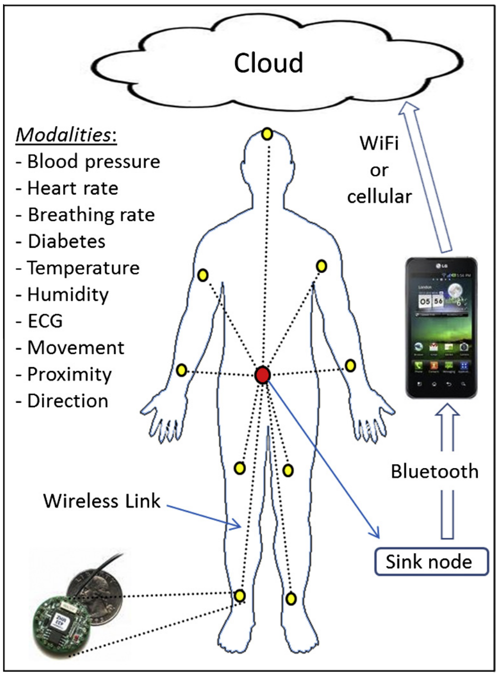

Fig. 1. Wireless body area networks system prototype.

which is usually a wider geographic area compared with the WiFi. It was shown that, via cellular, the transmission power of data packet of size 46 Bytes will cost about 300 mw and with a delay of 0.45 ms [29,31,32]. While the cellular connection is very costly in terms of power, transmission delay and connection cost (the WiFi is mostly free of charge), it's very important to support WBAN users mobility in case of the absence of the cloudlet in the range and to support the scalability of the system under large number of WBAN users, as we will discuss in Section 4.

Supporting mobility of WBAN users is one of the main contributions of the proposed model. Therefore, in our implementation, a random way point mobility model is used to represent a WBAN users mobility. At any given point in time and for a given area, the mobile user can be in one of following three regions: (1) Cloudlet Region (CR): in this region WiFi coverage is available, where a user can use the WiFi technology to transmit a data packet to the cloudlet. (2) Enterprise Region (ER): in this region only cellular coverage is available, where a user can use only cellular technology to transmit a data packet to the enterprise cloud. (3) Not-covered Region (NC), where neither WiFi nor cellular technology is available. In this case a user should buffer the packets until one of the above technologies is available, then to be able of transmitting the packet to the enterprise cloud. With random way point mobility a user can move from one region to another, therefore the mechanism of transmitting the data packet depends on the covered region, as we will discuss in Section 4. On the other hand, the WBAN users are able also to receive a data that is transmitted either by the near cloudlet or the enterprise cloud. Such data could contain some controlling, queries or alarm messages for a specified WBAN user.

3.2. Cloud system prototype

The objective of this section is to develop Cloudlet-based WBANs prototype system. The system prototype aims to demonstrate the capability of the proposed model to achieve the above-mentioned objectives. In this prototype, we extend the implementation of *CloudSim* [33] simulator tool, as in *Teachcloud* [34], to realize our Cloudlet-based WBANs model. *CloudSim* is a well-known cloud-based simulator tool which was developed at the University of Melbourne, Australia. The original implementation of *CloudSim* did not include any components for cloudlet or WBANs. The required components that are serve WBANs and cloudlet have been developed in this prototype and then integrated with *CloudSim* simulator in order to evaluate the proposed model. Then, the developed *CloudSim* simulator will be available to the public.

Cloudlet system represents a fully cloud system capabilities but in small scale. It may vary from a workstation like system to a more complex set of physical servers. Cloudlet uses a virtualization middleware that translate its hardware components to a set of virtual components enclosed in virtual machines (VMs). Each virtual machine will be assigned to a part of the available hardware resources. The hardware resources could be ranging from one CPU to a set of CPUs that support multi-core technology. Cloudlet system is also equipped with sufficient memory capacity per physical server. More memory capacity will help the cloudlet system to support more VMs efficiently. It is also contains a moderate size of storage capacity that may be reach to Terabyte scale. To support the main functionalities of the system, the cloudlet must support a set of transceivers (i.e. antenna) that is capable of receiving and sending the data packet from and to the WBAN users. Each cloudlet includes Multi Input Multi Output (MIMO) capabilities to support the cloudlet scalability in case of large number of users, simultaneous sending and receiving of data and high data transmission rate. Cloudlet antenna supports many wireless communication technologies, such as WiFi and WiMAX. WiFi is mainly used for short range and low power data transmission, like WBAN users in our case. While, WiMAX technology is used for long transmission range for inter-cloudlet communication. Cloudlet can be connected with other cloudlets or with the enterprise cloud using a wired communication system that supports high speed and large data rate. The cloudlet entity can be mobile depends on the usage scenario. But for simplicity in this study, the cloudlet entities are fixed in known geographic locations. Table 1 summarizes the cloudlet entity used in our *CloudSim* implementation.

The enterprise cloud system represents the conventional cloud system that can be private cloud system or public cloud service provider. The architecture of the enterprise system is mostly same architecture as in cloud based data centers with all its components and features. In our implementation, the enterprise cloud system will be the ultimate destination of the

Table 1
Cloudlet entity description.

Item	Cloudlet entity used
Industry Standard Architecture (ISA)	×86
Operating system	Linux
Virtual Machine Monitor (VMM)	Xen
Virtual machine allocation policy	Allocate VM to the host with lowest utilization
Storage capacity	1 Terabyte
Number of CPU	2 with 4 cores per CPU
MIPS for each core	2660
Memory capacity	8 GB
Virtual machine scheduler	Space shared
Bandwidth	10 Mbps
Communication technology	WiFi with 100 meter range, WiMax with 15 km range

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collected data. The enterprise cloud is also able to send messages back to both the cloudlet system or to WBAN users with specific task to perform or like a precaution from the service provider to a patient.

3.3. Virtualized vs. conventional server characterization

Simulations were carried out using extended version of *CloudSim* for observing the impacts of using Virtualized Cloudlet (VC) and Conventional Server (CS) on the performance metrics, like power consumption and processing delay. In these set of experiments, human subjects with WBAN, as shown in Fig. 1, are moving in a circle area with a radius of 100 m and centralized with a Base Station (BS) of cloudlet or conventional server for data collection. Each experiment is lasting for 3600 s. or one hour. The number of human subjects is ranged from 10 to 150 users. The human subjects are moving using random way point model with a speed of 2 m/s and a random pause time of 1–10 s. The proposed mobility scenario in this paper represents a real life application of moving students, soldiers or firefighters in a closed area [28,35–38]. Each user sends a data packet to the BS or the VC using WiFi with a rate of 0.1 Hz and packet size of 46 Bytes. The speed of processing the received data packet at the BS is varied between 100 and 900 Million Instructions Per Second (MIPS). The variation of MIPS here depends on the task load of the received data.

Fig. 2 shows the power consumed and the processing delay at the BS. In the figure, the number of Virtual Machines (VM) used in VC or VM–VC is set to be 2, 4 or 8. For a given one VM in the BS, the BS is called CS. The following observations can be made from Fig. 2. First, the data collection with Virtualized cloudlet system provides the opportunity of better system scalability in two folds, which are increasing the number of users in the covered area and dealing with different WBANs tasks loaded by providing diverse MIPS per task. Second, for a given MIPS task, the trends of power consumption and processing delay are increased by increasing the number of users for all given BSs architecture. The primary reason of increasing the power and delay is increasing the task load at the BS which needs more power and time to complete each user task. Third, the slope of power consumption and delay is decreased by increasing the number of VMs, that is due reducing the processing time in the BS by increasing the number of VMs. In these results, CS shows the highest power consumption and processing delay because only one VM is used in the machine.

The fourth observation that can be made from the processing delay results in Fig. 2 is the processing time is decreased by approximately 85% by using cloudlet system configured with 8 VMs comparing to using only one VM in CS. The delay results also revealed the scalability of cloudlet system with increasing of the task size or MIPS. Fifth, less than 20% of power and delay increase is induced by increasing the MIPS by 200 MIPS, as shown for instance with VMs of 2 in Fig. 3. It should be clear in these results that WBANs workload is generally characterized with vary and low MIPS size. Finally, the power results show that the power consumption is decreased by increasing the number of VMs. These results can be explained by sharing the cloudlet resources by more number of VMs will only increase the power consumption slightly. If we used 8 CSs instead of using one system with 8 VMs, the power consumption will be 11 times higher. The power results also scale well with increasing the task MIPS as shown in Fig. 4. In this figure, the average power is decreased by increasing the number of VMs. On the other hand and for a given BS, the average power is increased by increasing the task MIPS. Similar trends are observed for CS, 2 VM–VC, 4 VM–VC and 8 VM–VC.

4. Cloudlet-based WBAN model formulation

This section presents an experimental characterization of Cloudlet-based data collection in WBAN.

4.1. Cloudlet-based WBAN system model

Multi-WBANs data collection presents a crucial challenge due to a huge data communication, storage and processing requirements, as we discussed in Section 1. Current state of the art solutions does not successes to provide a technique that is handling such requirements. Data collection of WBAN users may need a costly broadband communication technology such as 3G and LTE. Fig. 5 shows a top level overview of our proposed Cloudlet-based WBAN data collection system. The system is composed of sets of WBANs. The WBANs are composed of multiple users (each user is equipped with WBAN as shown in Fig. 1), who are able to transmit the collected data by the WBAN to the outside of the body, as described in Section 3 and Fig. 1. A group of WBAN users can be virtually clustered around one cloudlet server that is representing cloud computing capabilities in a small scale which is sufficient to handle a WBAN user within the cluster, as we discussed in Section 3. In order to avoid the MAC-CSMA collisions characteristic in WBAN data packets, a pooling-based MAC protocol is applied.

The cloudlet system is composed of set of physical servers with many cores and huge Gigabytes of memory. The cloudlet server system is equipped with one or more of the communication antennas that is supporting different physical layer capabilities (e.g. WiFi and WiMax). The most important part of the cloudlet server is the storage system. The storage system should provide scalable and reliable environment for storing large data size. Different cloudlet systems could be connected with each other using wired or wireless communication links (e.g. WiMax). Furthermore, cloudlet system could be connected directly to an enterprise cloud system using wired or wireless communication links [39]. The enterprise cloud system is a centralized management and storage point that can be accessed by different organizations that are interested in a certain type of data. Another important feature of the cloudlet system is the ability of bidirectional communications between many

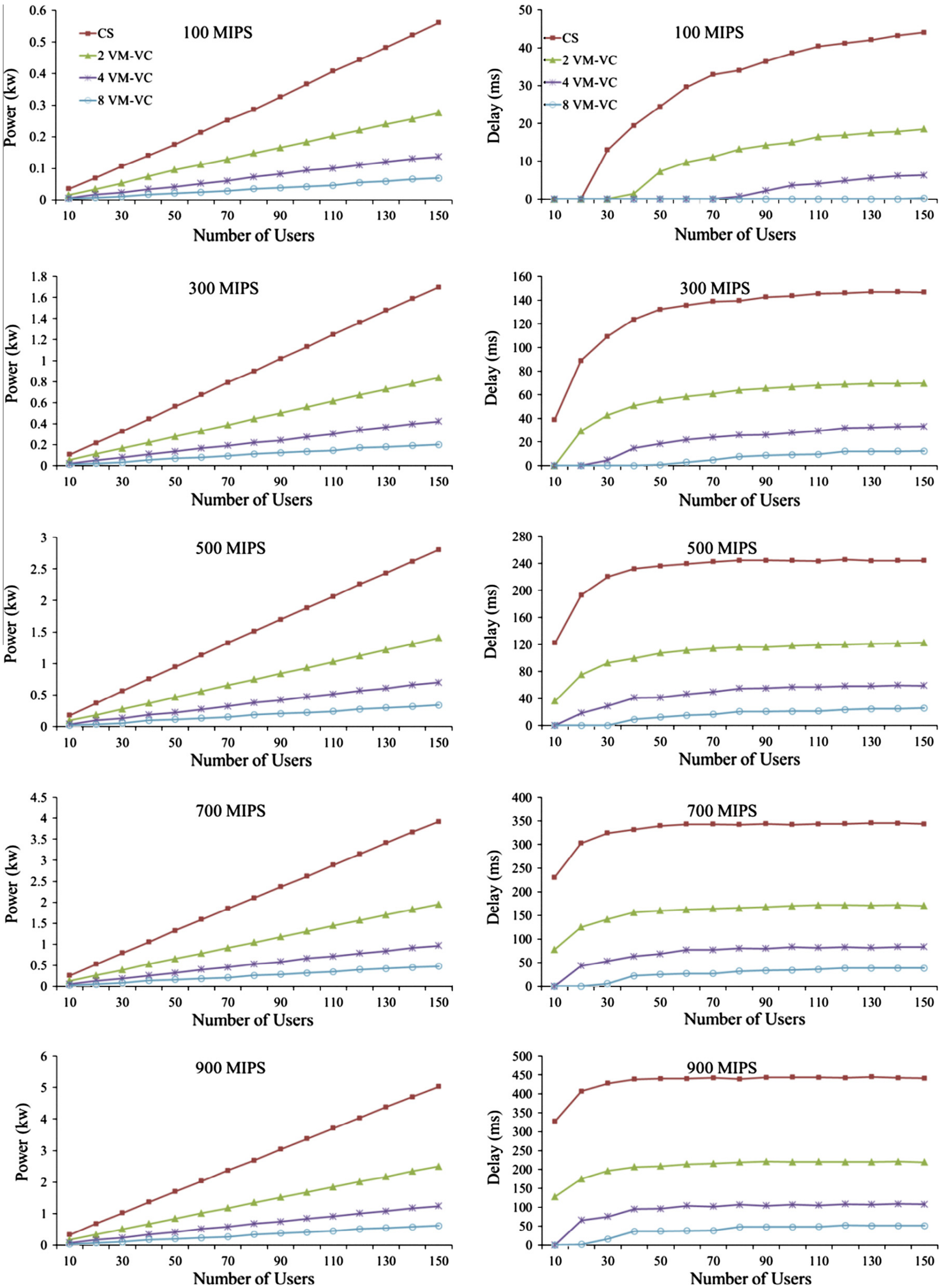

Fig. 2. Power and processing delay vs. number of users.

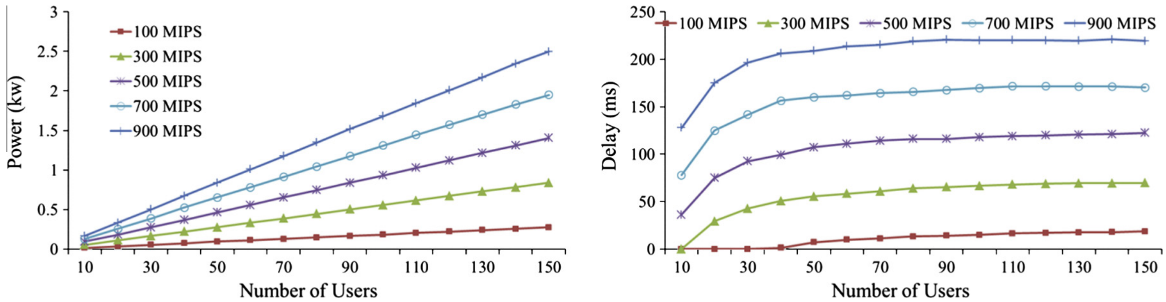

Fig. 3. Power and delay vs. number of users with 2 VM.

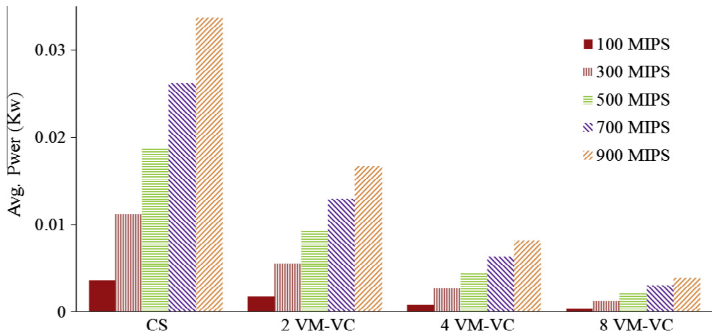

Fig. 4. Average power consumption for a given VMs and MIPS.

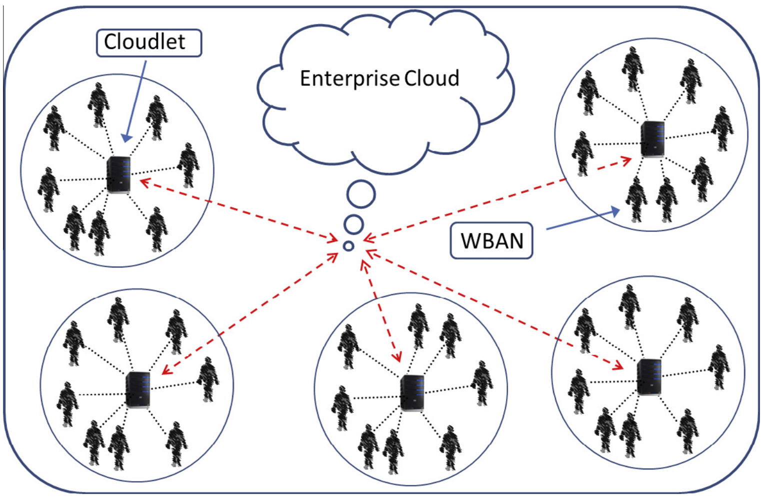

Fig. 5. Cloudlet-based WBAN data collection system exemplar.

WBANs users. In addition to its ability to receive data from multiple users, the cloudlet system is also able to communicate with multiple users based on the usage scenario.

4.2. Performance metrics

The performance of cloudlet-based WBAN data collection is evaluated using two generally used [40,41] primary metrics, namely, *Packet Transmission Power* and *Packet Delay*. The *Packet Transmission Power* and *Packet Delay* are directly measure of the communication energy and delay expenditure from the Personal Digital Assistant (PDA) device to the cloudlet or the enterprise cloud as shown in Fig. 1. Where on-body energy drainage and delay due to sensing and packet routing depend on the specific application, and are beyond the scope of this paper. We quantify both WBAN-to-cloud transmission power

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and delay needed to monitor set of WBAN users within specific period of time. It is obvious that the variation of delay and power results will come from the percentage of transmitted packets within cloudlets coverage using WiFi technology to the percentage of transmitted packets to the enterprise cloud using cellular technology. The goal is to minimize *Packet Transmission Power* while also minimizing the *Packet Delay* by having a user within cloudlet coverage, as described in Section 3.

4.3. Characterization of cloudlet-WBANs

In order to study the impacts of installing cloudlet servers on the data collection performance in the monitoring area, the following experiments were carried out. 400 users were moved in a random waypoint model within a monitored area of 600×400 m. The users are moved in random waypoint mobility in the area with a speed of 2 m/s and a random pause time of 1–10 s. The monitored data of WBANs from each user is collected then sent it to the cloud via WiFi or cellular technologies in a rate of 0.1 Hz with a total of 360 packets were sent from each user during 1 h experiment. In these set of experiments the number of deployed VCs is ranged from 0-VC to 6-VC. With 0-VC, it means that there is no VC in the monitored area, and the user data packet has to be sent via cellular technology to the enterprise cloud. Fig. 6 shows the deployment of VCs in the area, where 6-VC corresponds to the maximum number of VCs in the monitored area without any overlapping between the VCs. Remember, the VC can cover a circle area of radius 100 m, which is the maximum transmission range by using WiFi technology, as reported in Section 3.3.

Fig. 7 shows the performance results of the transmission power and delay for each scenario of VCs shown in Fig. 6. In Fig. 7, each transmission power and delay points in the *y*-axis correspond to the average of 10 different experiments, where each point in the figure shows the average power and delay per user and per packet. The following observation can be made from Fig. 7.

First, the 0-VC scenario shows the worst performance in terms of power and delay, where the packet transmission power was 300 mw and packet delay was 0.45 ms per user and per packet. The reason of that is each subject has to send the data packet to the enterprise cloud directly using cellular connection, which is very costly in terms of power and delay, as discussed in Section 3.3. Then, the trends of the power and delay results go down by increasing the number of VCs in the area, until the 6-VCs scenario. The values of power and delay results show 80mw and 0.12 ms, respectively. The 6-VC scenario shows the best case of having the maximum number of VCs to cover the area without overlapping between them. The final conclusion that we can made from Figs. 6 and 7 is the cost of data collections from the WBAN users can be reduced by increasing the number of CVs in the monitored area.

5. Experimental results

In this section, other sets of experiments were carried out, in order to study the impact of the number of users and the deployed VCs in the monitored area on the performance results. On the other hand, increasing the number of VCs will also increase the cost of monitoring, as described in Table 1. So, the objective of this section is to evaluate the prototype system for a given scenario of monitored area, number of users, number of VCs and the way of how these VCs are deployed.

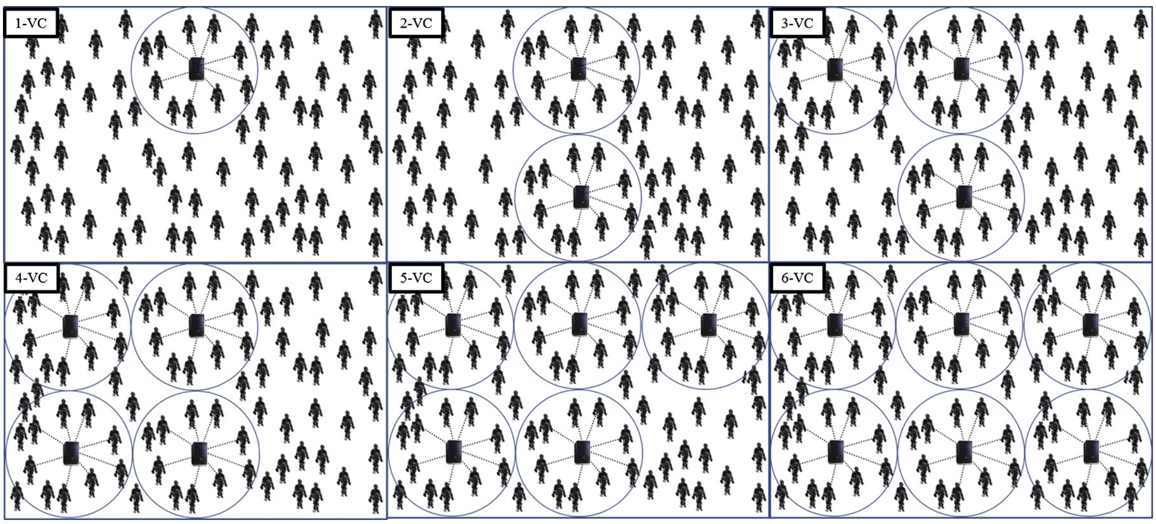

Fig. 6. VCs deployment in the monitored area.

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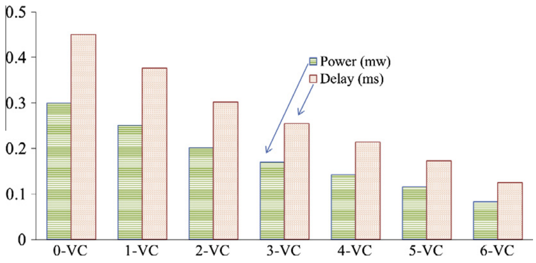

Fig. 7. Average transmission power and delay using VCs as shown in Fig. 6.

5.1. Number of users

In order to study the impact of the number of monitored users on the performance results, an area of 600 × 400 m was covered with 6-VCs without overlapping between the VCs as shown in Fig. 8. The number of users is set to be 400, 600, 800, 1000, 1200 and 1400. The users are moved in random waypoint mobility in the area with a speed of 2 m/s and a random pause time of 1–10 s. As shown in the figure, there are a certain number of users are within the VCs and other number are off the VCs areas, then they will not be able to use any VC to transmit the collected data to the enterprise cloud. Fig. 9 shows the performance results of these sets of experiments. The following observations can be made from Fig. 9. Both the average packet power and delay are increased by increasing the number of users in the area. That is because increasing the number of users in the area will increase the possibility of increasing the number of users in the off VCs regions, which will increase the power and delay of transmitting the packets using the cellular communication. On the other hand, each VC region is able to serve a certain number of users which is very similar to the WiFi capacity [30,31] and as we discussed in Section 3.1. Then, the extra users within the VCs have to send the data via the cellular communication, even though, they are within the VCs. It can be shown that the number of users that can be served by the WiFi with the VC is 120–150 users [30,31] and also be shown in Fig. 9.

5.2. VCs deployment and number of users

The second set of experiments were conducted in order to explore how the number of VCs and the way of deployed in the monitored area are impacting on the performance results by varying also the number of users. The rationale behind this study is to show the reader how the deployment mechanism will impact on the power and delay. A monitored area of 800 × 800 m was covered with different scenarios of VCs deployments, like with 4-VC, 5-VC, 6-VC, 8-VC, 10-VC, 12-VC, 14-VC or 16-VC, where the 16-VC scenario is the maximum number of VCs that can be deployed in the monitored area without having an overlapping between coverage areas. Please notice that, in all VCs deployments scenarios, we did not include

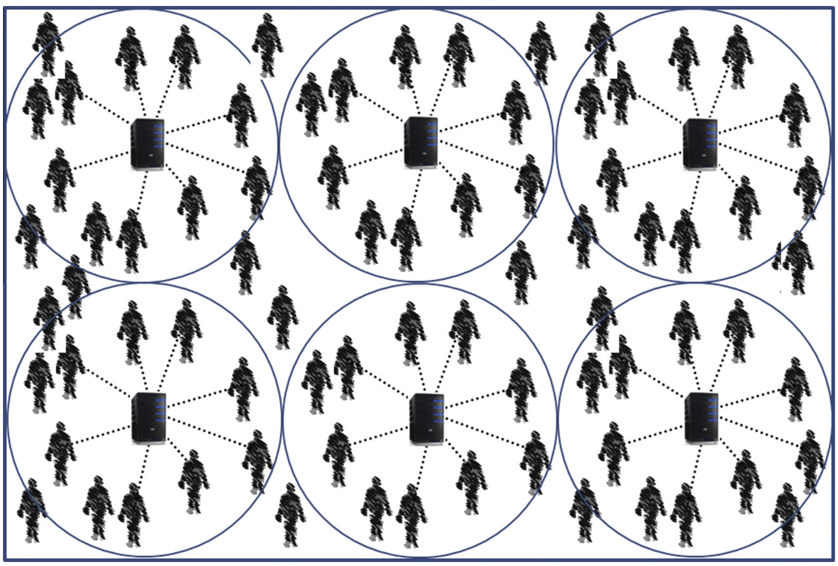

Fig. 8. Monitored area with different number of users and 6-VCs.

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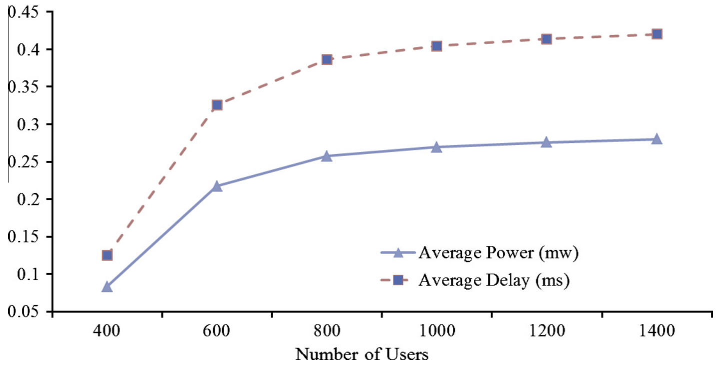

Fig. 9. Average power and delay with different number of users.

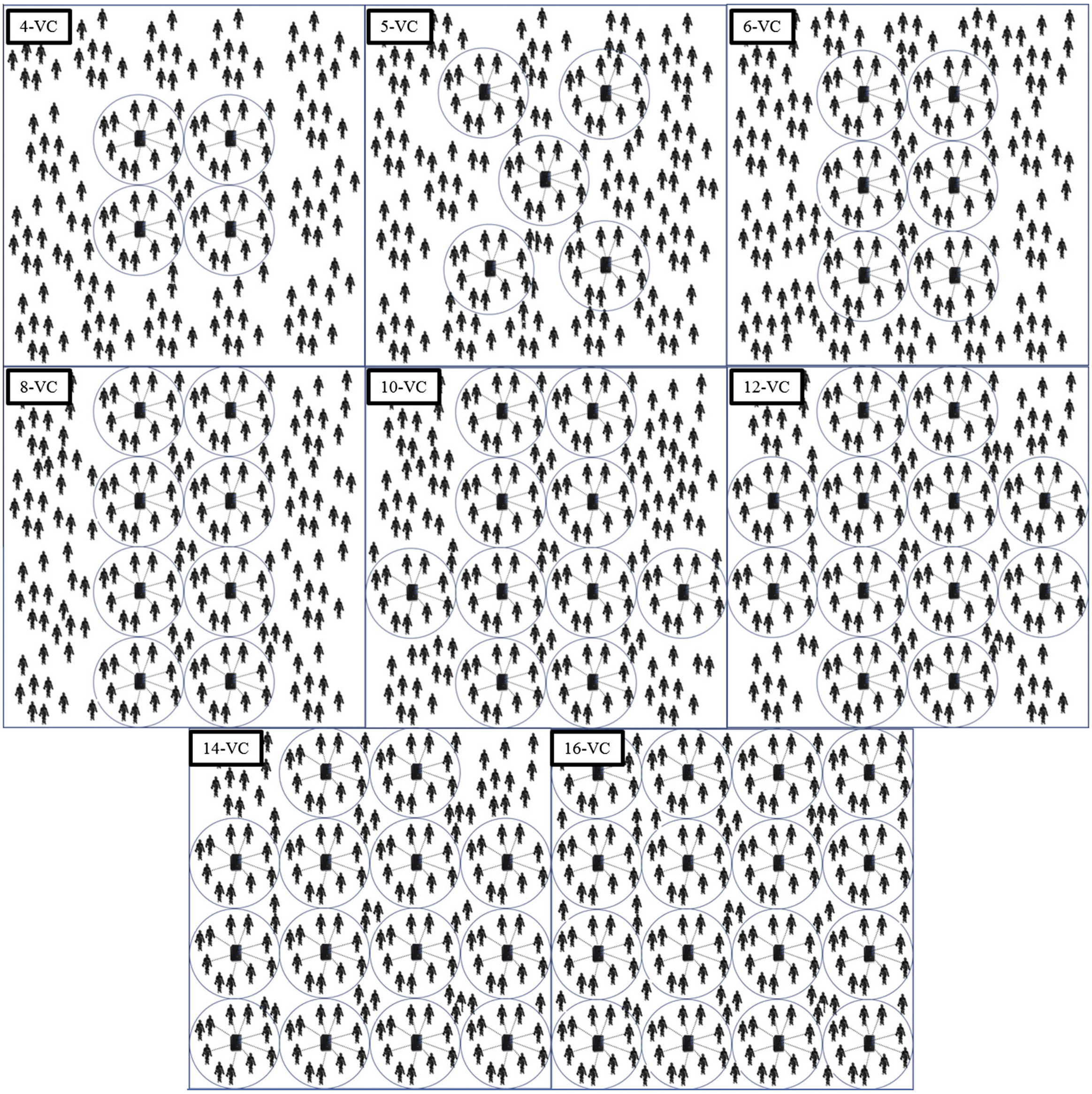

Fig. 10. Monitored area with adjacent VCs.

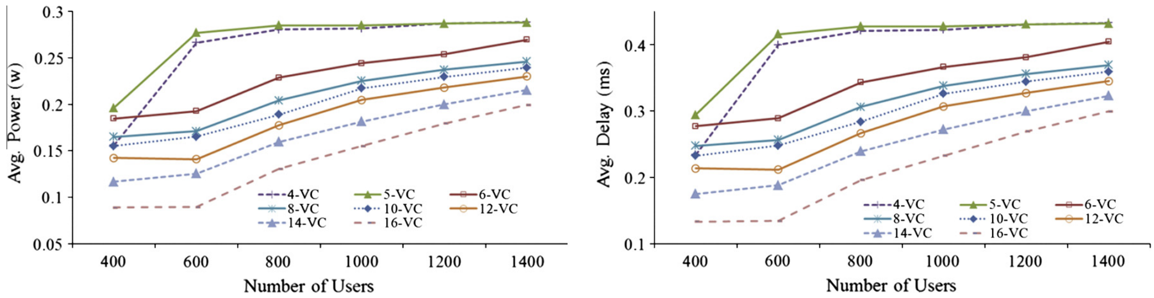

Fig. 11. Average power and delay with adjacent VCs and different number of users.

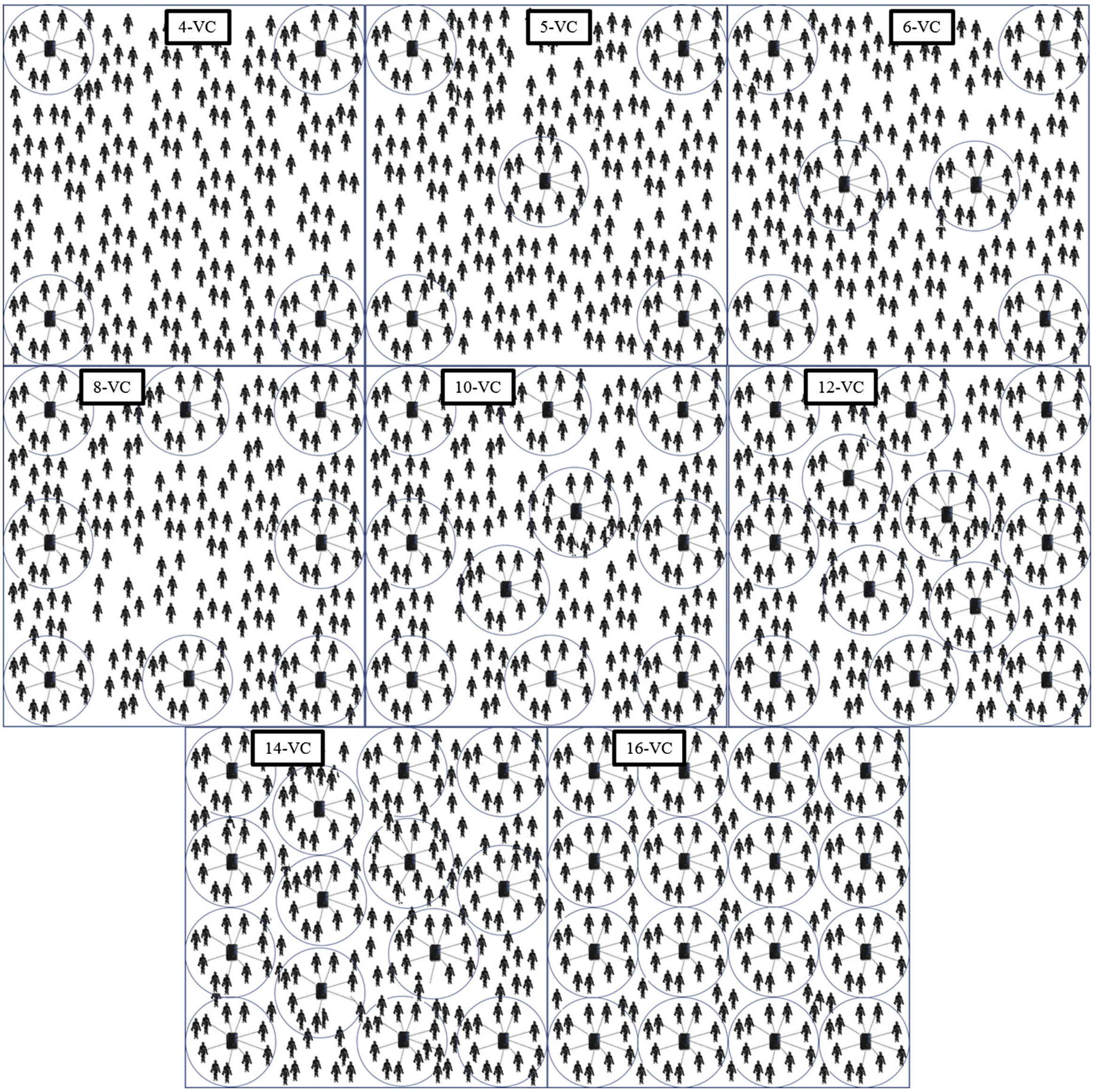

Fig. 12. Monitored area with distant VCs.

any overlapping scenario between the VCs in order to have the minimum cost of VCs in the monitored area. For a given VCs deployment scenario, the number of users is also set to be 400, 600, 800, 1000, 1200 and 1400 and they are moved with random way point mobility with a speed of 2 m/s and a random pause time of 1–10 s. In this set of experiments, the deployment of VCs is categorized into three categories, *Adjacent*, *Distant* and *Intermediate* deployment, as we will discuss in next sections and Figs. 10, 12 and 14.

5.3. Adjacent VCs deployment

In this set of experiments, the monitored area is deployed with a relatively adjacent VCs in order to see how that will impact on the performance results. The idea of having adjacent VCs is to reduce the cost of the distant between the VCs for a given application. Fig. 10 illustrates the adjacent VCs deployment in the monitored area and Fig. 11 shows the corresponding performance results of power and delay.

The following interpretations can be made from Figs. 10 and 11. First, increasing the number of VCs in the monitored area will reduce the average power and delay of the collected data, because increasing the VCs will increase the opportunities of the users to send the data packet to the corresponding VC using WiFi and with minimum cost of power and delay, rather than of using cellular connection. The second observation that we can made from Fig. 11 is, increasing the number of users for a given VCs deployment, will increase the power and delay of the collected data. That is due to increasing the number of users will increase the number of users in the off area of the VCs. In the same time that will increase the capacity of users in the VC will make the extra users to use the cellular connection to send the data, as we discussed in Section 5.1 and Fig. 9.

5.4. Distant VCs deployment

The monitored area in this set of experiments is deployed with a relatively distant VCs. Fig. 12 illustrations the distant VCs deployment. As seen in the figure, with few numbers of VCs, it shows clearly how the VCs are distant. But by increasing the number of VCs for a given area, the impact of distance on VCs deployments is vanished. Fig. 13 shows the performance results of power and delay for the conducted experiments in Fig. 12. Similar observations from Fig. 13 can be made as in Fig. 11. The average power and delay are generally decreased by increasing the number of VCs and decreased by increasing the number of users. Same results also can be concluded by conducting similar experiments with intermediate VCs deployment. Fig. 14 illustrates the results of the intermediate VCs deployment.

In order to compare between the different distance deployments VCs, the results in Figs. 15 and 16 are generated. These figures show the average power and delay for the Adjacent, Distant and Intermediate deployment of VCs, including 4-VC, 5-VC, 6-VC, 8-VC and 10-VC. The number of users are used to generate these results is 800 users. As we discussed before,

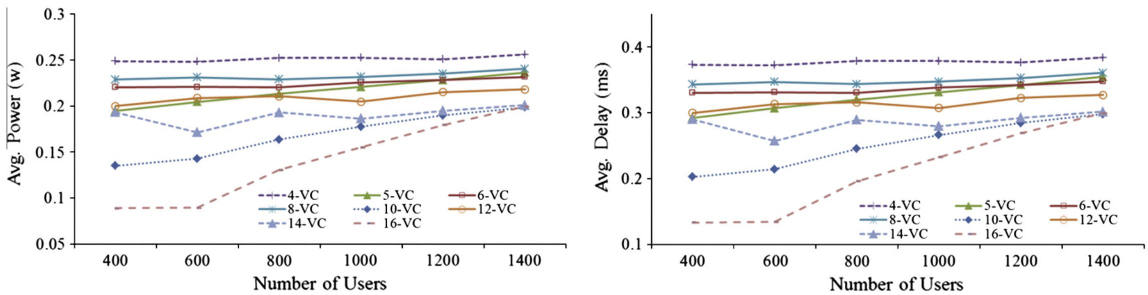

Fig. 13. Average power and delay with distant VCs and different number of users.

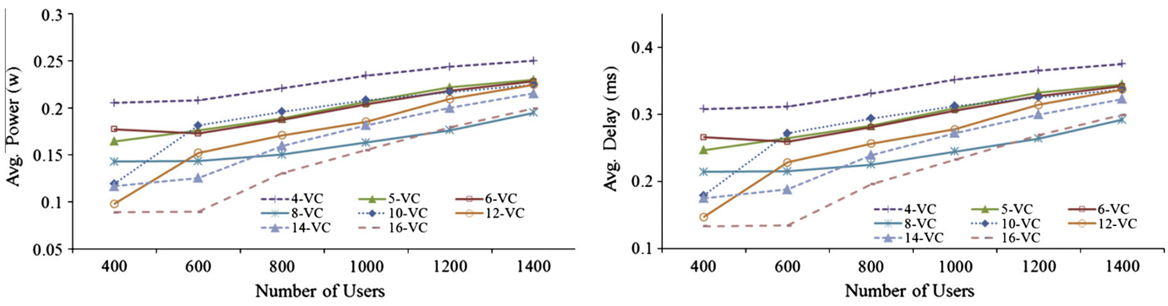

Fig. 14. Average power and delay with intermediate VCs and different number of users.

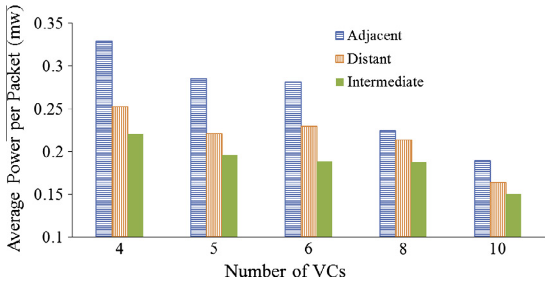

Fig. 15. Average power with different VCs deployment scenarios.

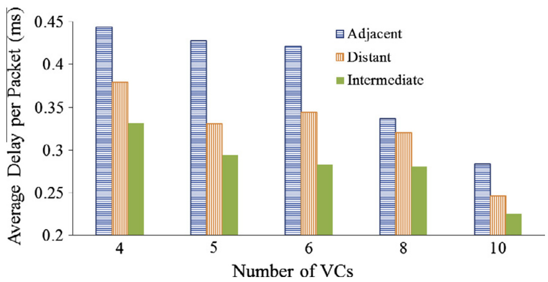

Fig. 16. Average delay with different VCs deployment scenarios.

the impact of distance on VCs deployments is vanished by increasing the number of VCs for a given area. The results in Figs. 15 and 16 show that, increasing the number VCs will decrease the average power and delay, as we discussed before. On the other hand, the difference in the results between the three deployments is decreased by increasing the number of VCs, because the distance is disappeared by increasing the number of VCs. The other important conclusion that we can made from these results is that, the Intermediate VCs deployment results show lower power and delay compared with other deployments (Adjacent, Distant), for the given random way point mobility. That is because of the user's mobility distribution according the random way point in the given area [42,43].

6. Conclusion and ongoing work

An efficient data collection for large scale WBANs system is presented in this paper. A prototype of WBANs, including Virtual Machine and Virtualized Cloudlet has been proposed and evaluated using extended *CloudSim* simulator. Using the prototype system, we provide a scalable storage and processing infrastructure for large scale WBANs system. The objective was to decrease the power and delay of the collected data by dynamically choosing data communication technology in the monitored area. It was shown that the proposed model is fully supporting for WBANs system mobility using cost effective communication technologies of WiFi and cellular communications which are supported by WBANs and VC systems. It was shown that the performance of the average power consumption and delay of the collected data is enormously decreased by increasing the number of VCs in the monitored area. It was also shown that increasing the number of users in the monitored area will increase the average power consumption and delay of the collected data. Ongoing work on this topic includes developing a prediction model like, Kalman Filter for user mobility prediction, in order to predict the mobility of the user in the monitored area and to decide the locations of the deployed VCs.

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