# Analysis of ”Cloudlet-based Efficient Data Collection in Wireless Body Area Networks” report

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# Introduction and research's goal

- What is meant by WBAN (**Wireless Body Area Networks**)?
- What are the **objectives** of Quwaider and Jararweh [4] research?

> *"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 [...] reducing packet-to-cloud energy, the proposed work also attempt to minimize the end-to-end packet delay."[4, par. 1.4]*

- In other words, the goal of their work is to built an *efficient* WBANs exploiting **edge computing paradigm**, in order to **minimize average power consumption** and **transmission delay** when **Personal Digital Assistant** (**PDA**) of any WBAN user transmits collected data.

# Analysis of existing WBANs implementations

- Why Quwaider and Jararweh [4] state that existent solutions aren't optimal for WBANs applications?
  1. They are based on cloud computing paradigm which has several disadvantages, the most important of which is **latency** problems.
  2. They exploit **cellular network** as communication technology.

> *"It was shown that, via WiFi, the transmission power of a data packet of size 46 Bytes will cost about 30 mw 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, 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."[4, par. 3.1]*

# The role of communication technology

- According to researchers, the role of communication technology is **critical for energy consumption reduction**:
  - all research is based on the observation according to which using WiFi communication technology a WBAN user is able to transmit data packet to the enterprise cloud with **low power consumption**, **low delay** (**not always!**) and mostly **no connection cost** compared with cellular communication technology.
- How to exploit WiFi technology in WBAN systems taking into account its **short transmission range** compared to cellular network?
  - Providing an edge computing infrastructure made up of several cloudlet geographically distributed and equipped with computational, storage and communication capabilities.

# The role of edge computing

- According to researchers, the role of communication technology is **critical for transmission delay reduction**:
  - deploying cloudlet *close* to final users, thanks to **high-bandwidth single-hop connection**, is possible to reduce RTT and to increase end-to-end bandwidth; in other words, we can achieve **network-proximity**.[6]
  - However, is very important to not confuse *physical proximity* with *network-proximity* (**!!!**)

# The role of edge computing

- Be aware that researchers solution is *still* using *cloud* resources.
    - Cloud plays a very important role in this kind of system, because its resources are exploited to overcome WBAN devices constraints.
    - Cloud represents, in terms of archival preservation, the *safest place to store data*, ensuring the long-term integrity and accessibility, and the *main execution site to perform expensive computations*, thanks to its almost unlimited **elasticity**.

# The role of edge computing

*"In our implementation, the enterprise cloud system will be the ultimate destination of the collected data. The enterprise cloud is also able to send messages back to both the cloudlet system or to WBAN users."[4, par. 3.2]*

*"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."[4, par. 4.1]*

# The role of edge computing

- Quwaider and Jararweh [4] have built a system, capable to exploit edge computing resources, intended for so called *edge-accelerated, cloud-native applications*. [6][5] In fact:

  cloud-native
  : because, to overcome stringent constraints on battery, performance and storage of WBAN devices, cloud resources are exploited, through offloading techniques over a wireless network, **to execute critical task**; in other words, as stated also by Quwaider and Jararweh [4], *cloud is the primary execution site and it is essential to provide services to final users*.

  edge-accelerated
  : because the system exploits edge computing resources **only when available**. In that way, that system is capable to provide optimal performance, but *edge resources represents a secondary execution site, that is they are optional to provide services*.

# A self-adaptive system

- Quwaider and Jararweh [4] implemented a *self-adaptive behaviour* according to which **communication technology is dynamically changed** when users move from one region to another.
- Quwaider and Jararweh [4] have identified three different regions:[4, par. 3.1]

  Cloudlet Region (CR)
  : where WiFi coverage is available, so a user can use it to transmit data to the cloudlet.

  Enterprise Region (ER)
  : where only cellular coverage is available, therefore a user can use only cellular technology to transmit a data packet to cloud.

  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.

# A self-adaptive system

- In other words, WBAN users are capable to exploit edge computing resources if and only if they are in a *Cloudlet Region*, otherwise they go on transmitting data directly to the cloud. (in fact, that solution is edge-accelerated, cloud-native application)
- From a deployment point of view, this system represents a **distributed self-adaptive system** since a self-adaptive software, including both *managed software* and *managing software*, is deployed in every WBAN users device.[7]
- From decisions control point of view, we can consider it a **decentralized self-adaptive system** too due to the lack of a central control component that decides about when and how to perform an adaptation.[7]
  However, is very important to precise that in Quwaider and Jararweh [4] system there is **no coordination** between WBAN nodes referring to control decision. All of them act independently, deciding adaptations autonomously, therefore, *any kind of control decisions decentralization pattern is been used*.

# A self-adaptive system

- From an architectural point of view, that system uses a **top-down approach** based on **MAPE-K feedback control loop**. Researchers wrote that:

  > *"each VC region is able to serve a certain number of users [...] Then, the extra users within the VCs have to send the data via the cellular communication, even though, they are within the VCs."[4, par. 5.1]*

- In other words, *WBAN devices exhibit a behavior according to which they can decide to offload towards cloud instead of cloudlet if Wifi network is highly congested*. This point is very important because an highly congested WiFi can lead to high latency, therefore, in accordance with policies established by Quwaider and Jararweh [4], WBAN nodes send data cellular communication, even though, they are within a cloudlet region.

# A self-adaptive system

**Knowledge/Goal** The goals established by Quwaider and Jararweh [4] are average power consumption and average transmission delay minimization.

**Monitor** The monitoring process is responsible for collecting data from environment like network quality and WiFi or cellular connection availability.

**Analyse** Measured data are analysed in order to detect WiFi congestion condition level (”Low” or ”High”) and check what is the current region (”NC”, ”ER” or ”CR”) where user is.

**Plan** Select and plan a solution to achieve established goal in according to system state diagram (**see the report!**)

**Execute** Change communication technology according to current state.

# A self-adaptive system

- Finally, Quwaider and Jararweh [4] solution can be considered as **application-transparent** since WBAN applications are *not* informed that a communication technology change is occurred; in other words, underlying system is the only responsible for the adaptation. In this way, compatibility with already existing applications is assured, although adaptations can affect negatively on WBAN applications.

# The use of cyber-foraging techniques

- Obliviously, WBAN devices cannot have enough computation and storage resources to manage that amount of data due to their very strictly constrains in term of size and power consumption. In order to overcome limitations of mobile devices used in WBAN, Quwaider and Jararweh [4] adopt several **cyber-foraging techniques**.
- Quwaider and Jararweh [4] have adopted **data staging** tactic too in order to improve WBAN applications performances managing **field-collected data**. In fact, when a WBAN application complete all its data collection operations, following situations may happen:
    - If a WBAN user is close to a cloudlet, WBAN devices offload data to cloudlet and, when the operation is complete, they delete transmitted data to free up storage space. In addition, cloudlet forwards to enterprise cloud all data that was collected by the multiple users.
    - If a WBAN user cannot establish a connection with a cloudlet and a cellular data connection is available, all collected data will be offloaded directly to the cloud.

# The use of cyber-foraging techniques

- In other words, is clear that external resources are located in both **single-hop** and **multi-hop** proximity of the mobile devices that use them. In fact, when collected data are offloaded to a remote resource, that is enterprise cloud, **synchronous operations with multiple network hops** between the mobile device and the cloud are involved while, when data are offloaded to cloudlet, a **single-hop connection** is involved (although is not clear if cloudlet need to be connected at runtime to cloud or not).

# The use of cyber-foraging techniques

- Quwaider and Jararweh [4] adopt a very static approach about offloading operations because, if a offload target is available, data will be **always** offloaded.
- This decision can lead to a negative consequence to **reduce resource efficiency** because, even though executing the expensive computation on a surrogate leads to energy efficiency, *changing network conditions might cause greater resource consumption*: if a WBAN node detects that WiFi network conditions are bad and decide to use cellular network, inevitably more energy will be consumed increasing transmission delay.

# The cloudlet discovery and provisioning issue

We believe that the cyber-foraging system built by Quwaider and Jararweh [4] is too simple to achieve research's goals, because it lacks of some very important features. In fact, it is shown that cyber-foraging systems have *at a minimum* the following combination of functional requirements [3]:

- A need for computation offload, data staging, or both.
- A need to **provision a surrogate** with the offloaded computation or data staging capabilities.
- A need for the mobile device to **locate a surrogate** at runtime.

# Cloudlet discovery issue

- Although WBAN users *need* to be able to locate available cloudlet in an area where stage data, **cloudlet discovery** issue has **not** been addressed by Quwaider and Jararweh [4]
- **cloudlet discovery** is very important because affects negatively energy consumption and response time and, anyway, it is a **functional requirements** for any cyber-foraging systems.
    - The problem of **selection algorithm** to select best cloudlet.
    - The problem of **security**.
- Possible solution? **Cloud surrogate directory tactic!**

# Cloudlet provisioning issue

- In the same way, **surrogate provisioning** is another functional requirements for any cyber-foraging systems which is **not** addressed by Quwaider and Jararweh [4], therefore is not clear how cloudlets manage offloaded computation and/or data processing operations.
- We will see later that Quwaider and Jararweh [4] had shown that **packet process delay** is affected by the number of virtual machine deployed in cloudlet. However, provisioning tactic affects this process delay too. It is shown that *pre-provisioned cloudlet tactic* have the advantage of shorter provisioning times because the capabilities already reside on cloudlet, providing shorter response times to requests from mobile devices.[3]

# Communication style

- When a device cannot transfer data packet to cloudlet for some reason, WBAN users are obliged to communicate directly with server-side application running on cloud, therefore a classical **client-server style communication** is adopted, which use classic *point-to-point* and *synchronous* communications.
- When a WBAN user is capable to communicate through a server, the system adopts a **loose-connector** communication style: **server-side client/agent/server model**. In that case, the *agent* is the cloudlet, which, acting as a surrogate to perform cyber-foraging tactics, is located on the so-called "*fixed*" side portion of the network and, precisely, on the edge of the network.

# First experiment set

First experiment set goal is to quantify both **packet process delay** and **power consumption**, due to packet computation, by cloudlet varying following system parameter.

1. number of virtual machine deployed on a cloudlet (0, 2, 4 or 8). The maximum number of deployable virtual machines is bounded by the number of physical processors available on cloudlet (Quwaider and Jararweh [4] prototype cloudlet have 8 physical processors, therefore 8 is the maximum number of deployable VMs).
2. processing speed of data packet, from a minimum 100 to a maximum of 900 **million instructions per second** (MIPS).
3. number of WBAN users (up to 150 users).

# First experiment set: Results

- **Increasing the number of virtual machines running on a cloudlet, packet process delay will be reduced.**
  It is shown that, if data packets can be processed in **parallel**, the **blocked time** can be reduced. In fact, fixed data packet *average arrival rate* $\lambda$ and *average service rate* $\mu$ of each virtual machine, system cloudlet **utilization**, that is *the fraction of time according to which cloudlet is busy*, is reduced; each virtual machine, by symmetry, sees an arrival rate of $\frac{\lambda}{k}$, where $k$ is the number of deployed virtual machines. Therefore cloudlet utilization, which is equal to $\frac{\lambda}{k\mu}$, decrease increasing $k$. It is shown that, decreasing utilization, **blocked time** decreases.[1]

# First experiment set: Results

- **Fixed the average time required to process a packet data on a CPU, that is for a given MIPS process speed, power consumption and processing delay are increased by increasing the number of users.**
  This happens because cloudlet utilization increases because $\lambda$ is higher, therefore the fraction of time according to which cloudlet is busy increases too; so, since more time is needed to complete user tasks, more power is consumed.

# Second experiment set

Second experiment set was carried out in order to quantify advantages of using edge computing resources. To be more precise, that simulation monitors the effects on **average transmission power and delay** of data packed send by users PDA to cloudlet, varying following system parameters:

1. number of cloudlet deployed (from 0 to 6).
2. number of WBAN users (set to be 400, 600, 800, 1000, 1200 and 1400).

Monitored area size is fixed to $600 \times 400$ $m$.

# Second experiment set: Results

- As expected, increasing the number of available cloudlets in monitored area, average transmission delay of data packed is reduced. It happens since the probability that an user is close to one of them increases. Having more opportunities to transmit data within cloudlet coverage, users can benefit of *cloudlet network proximity*.
  In fact, when cloudlet coverage is available, data is offloaded to a cloudlet using a high bandwidth single-hop connection, which decrease RTT. Conversely, when cloudlet coverage isn't available, data is offloaded to cloud using a multi-hop network connections which involves high RTT and likely low bandwidth connection.[2]

## Second experiment set: Results

- Increasing the number of available cloudlets, average transmission power of data packed is reduced too. It is due to the use of WiFi technology which is, as already said, more energy-efficient compared to cellular network.

# Second experiment set: Results

- Increasing the number of users, both average transmission power and delay increase. This happens because:
    1. When a cloudlet area contains a large number of users, interferences increase, leading to higher error bit rate and affecting negatively both transmission delay, due to data packets or acknowledgements loss, and power, due to packet retransmission.
    2. Since a polling MAC scheme is used, an higher number of users within an cloudlet WiFi coverage area increases the time needed to pool every node by AP.
    3. As stated by Quwaider and Jararweh [4], an high congested WiFi network can cause WBAN devices to perform a self-adaptation action according to which communication technology is switched, using cellular network to send packet data instead WiFi, affecting negatively aforementioned metrics.

# Third experiment set

The last experiment set is focusing on monitoring aforementioned performance metric varying cloudlet geographical placement. Monitoring an $800 \times 800$ $m$ area, simulations were carried out varying following system parameters:

1. number of cloudlet deployed (up to 16 cloudlets).
2. number of WBAN users (up to 1400 users).
3. WBAN user's positions (same parameters as before)
4. cloudlet geographical placement (using very different patterns, classified in three categories by Quwaider and Jararweh [4]: *Adjacent*, *Distant* and *Intermediate*)

# Third experiment set: Results

Experiments results are the following:

- As expected, independently from cloudlet deployment pattern, increasing the number of cloudlet, the impact of cloudlet geographical placement on average transmission power and delay is negligible since, in that way, the opportunities to send the data packet to a cloudlet, using WiFi and with minimum cost of power and delay, increase.
- Fixed cloudlet and users number, deploying cloudlet using an intermediate category pattern, that is placing cloudlet neither too far apart nor too close, system performance are better than other patterns belonging to other categories.

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