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

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> *"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"(**?**, par. 1.4)*

According to **?**, the goal of their work is to built an efficient **Wireless Body Area Networks** (**WBAN**) exploiting **edge computing**, a new paradigm in which substantial computing and storage resources, referred to as **cloudlets**, are placed at the **Internet's edge**, that is in close proximity to WBAN devices or sensors.
To be more precise, as stated by **?**, edge computing resources are exploited in order to **minimize average power consumption** and **transmission delay** when **Personal Digital Assistant** (**PDA**) of any WBAN user transmits collected data.
How edge computing resources are been exploited by **?** to achieve their

The role of communication technology

The 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** and mostly **no connection cost** compared with cellular communication technology. In fact, researchers wrote:

> *"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."(**?**, par. 3.1)*

MAC protocol

- Medium access mechanisms used is **pooling-based**.
- This choice has several advantages:
  - is capable to offer time-bounded service, **guaranteeing a maximum access delay and minimum transmission bandwidth** making the system more **predictable** and, therefore, more suitable for **real-time** health monitoring.
  - Since WBAN users are not allowed to send data without the master's invitation, the **hidden terminal problem is eliminated**.
  - This scheme allow higher throughput due to less collisions respect to CSMA/CA.**?**

The role of edge computing

How to exploit WiFi technology in WBAN systems taking into account its **short transmission range** compared to cellular network? According to **?**, the answer is *providing an edge computing infrastructure made up of several cloudlet geographically distributed and equipped with computational, storage and communication capabilities*. Researchers wrote:

> *"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)."(**?**, par. 4.1)*

In other words, distributing geographically several cloudlets with aforementioned capabilities in a region, is possible to extend WiFi coverage increasing the probabilities that WBAN users use WiFi as communication technology. However, there are other reasons which

A self-adaptive system

Since WiFi technology transmission range is short and edge infrastructure resources are expensive, cloudlet and WiFi coverage aren't available everywhere. Therefore, **?** implemented a *self-adaptive behaviour* according to which **communication technology is dynamically changed** when users move from one region to another. This is the reason according to which **?** have identified three different regions:(**?**, 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.

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

The use of cyber-foraging techniques

WBAN sensors and devices collect a very huge amount of data. In fact, **?** wrote:

> *"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."(**?**, par. 1.1)*

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, **?** adopt several **cyber-foraging techniques** to exploit external resources to augment the computation and storage capabilities of WBAN devices extending their battery life. For instance, **computation offload tactic** is

The cloudlet discovery and provisioning issue

We believe that the cyber-foraging system built by **?** 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 **?**:

- 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.

The cloudlet discovery and provisioning 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 **?** in any way; we believe that it is a very big mistake because cloudlet discovery affects negatively energy consumption and response time and, anyway, it is a **functional requirements** for any cyber-foraging systems.
  Moreover, when you want to offload data or computation to a cloudlet, generally a **selection algorithm** to select best cloudlet is run. In WBAN systems, maximize energy efficiency, in order to preserve devices lifetime, is critical, therefore is preferable not run selection algorithm on WBAN devices, which can decrease energy efficiency (depending on the complexity of the algorithm and the number of monitored variables). Probably, using cloud surrogate directory tactic, according to which selection algorithms run on the cloud, is possible to improve WBAN lifetime. **?**
- In the same way, **surrogate provisioning** is another functional requirements for any cyber-foraging systems which is not addressed

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 (**?** 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* λ and *average service rate* μ 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.**?**

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 λ 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 600×400 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.**?**

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 **?**, 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 800×800 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 **?**: *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.

IEEE 802.11ah as communication standard

In addition to changing communication technology, we believe that the use of a communication standard capable to minimize the main sources of energy waste like *collision*, *inter-network interference*, *idle listening* and *control packet overhead* is extremely useful to maximizing the lifetime of WBAN devices.

Unfortunately, **?** give us very few details about MAC protocol, however is reasonable to assume that they have used legacy IEEE 802.11 protocol with 2.4 or 5 GHz bands.

We believe that we can achieve better communication performances over longer distances among a large number of low-power devices exploiting **IEEE 802.11ah**. In fact:

- The 802.11ah standard enables single-hop communication over distances up to 1000 m, utilizing sub-1 GHz license-exempt bands to provide better propagation characteristics in outdoor scenarios, like WBAN, than legacy WiFi. On the other side
- IEEE 802.11ah MAC layer improves power efficiency through frame shortening techniques, reducing overhead caused by short packets

Grazie per l'attenzione!