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"Sensor-cloud": Offering Useful Data Reliably to Mobile Cloud from Wireless Sensor Network

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Abstract— The integration of wireless sensor network (WSN) and Mobile cloud computing (MCC) is a research topic that is attracting growing interest in both academia and industry. In this new paradigm, WSN provides data to the cloud, and mobile users request data from the cloud. This paper first identifies the critical issues that affect the usefulness of sensory data and the reliability of WSN, then proposes a novel WSN-MCC integration scheme named TPSS, which consists of two main parts: 1) TPSDT (Time and Priority based Selective Data Transmission) for WSN gateway to selectively transmit sensory data that are more useful to the cloud, considering the time and priority features of the data requested by the mobile user; 2) PSS (Priority-based Sleep Scheduling) algorithm for WSN to save energy consumption so that it can gather and transmit data in a more reliable way.

Keywords- Wireless sensor networks, mobile cloud computing, integration, usefulness, reliability

1. INTRODUCTION

1.1 Integration of WSN and MCC

WIRELESS sensor network (WSN) is a distributed network, consisting of autonomous sensors that cooperatively monitor the physical or environmental conditions (e.g., sound temperature, humidity, vibration, etc.) [1] [2]. With the ubiquitous data gathering ability of sensors, WSN has great potential to enable a lot of significant applications in various areas of industry, civilian and military (e.g., industrial process monitoring, forest fire detection, battlefield surveillance, etc.), which could change the way people interact with the physical world.

Moreover, inherited from cloud computing (CC), which is a new computing paradigm enabling users to elastically utilize a shared pool of cloud resources (e.g., processors, storages, applications, services) in an on-demand fashion, mobile CC (MCC) further transfers the data storage and data processing tasks from the mobile devices to the powerful cloud [3].

The integration of WSN and MCC is attracting increasing attention from both academia and industry [4] [5]. Particularly, as illustrated in Fig. 1 about the general scheme (GS) to gather and transmit sensory data for WSN-MCC integration, the sensory data (e.g., weather, traffic, humidity, house monitoring information) collected by various types of always on sensors (e.g., video sensors, mobile sensors, static sensors) after data sensing, data storage and data processing, are transmitted first to the WSN gateway in a hop-by-hop manner.

The gateway then further stores, processes and transmits the received sensory data to the cloud. Finally, the cloud stores, processes and transmits the sensory data to mobile users on demand. During the whole data transmission process, if the data transmissions from the sensor nodes to the gateway or from the gateway to the cloud or from the cloud to the mobile user are not successful, data are retransmitted until they are successfully delivered. For this new WSN-MCC integration paradigm, the WSN acts as the data source for the cloud and mobile users are the data requesters for the cloud. With just a simple client on their mobile devices, mobile users can have

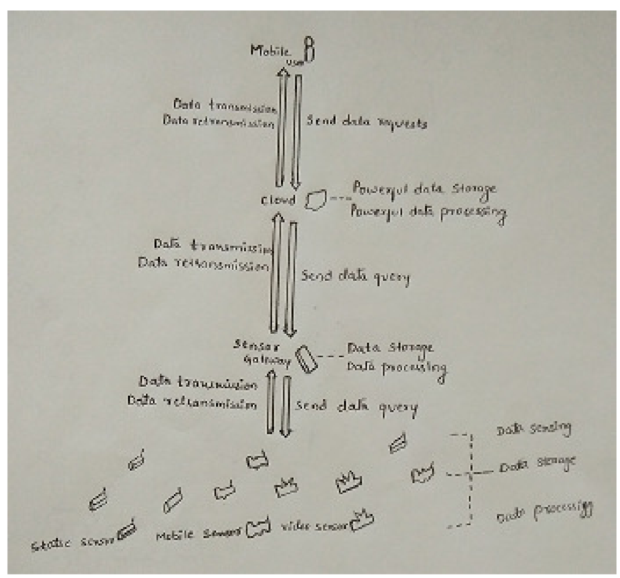

Fig 1: General scheme (GS) to gather and transmit sensory data for WSN-MCC integration

sensors as an interface between physical and cyber worlds, the data-compute clusters as the cyber backbone and the internet as the communication medium.

1.2 Motivation

In these potential applications of integrated WSNMCC [6], quite a number of them actually require the WSN to reliably offer sensory data that are more useful to the cloud based on the requests of the mobile users. Take smart house monitoring as an instance, although various monitored information about the whole house gathered by the strategically deployed video sensors, image sensors and other types of sensors can be offloaded to the cloud to let the owner of the house or other authenticated and permitted people conveniently access their desired data with the mobile devices (e.g., smart phones, tablet computers), it is expected that videos from some locations (e.g., storage room) are of little interest, while videos from other locations (e.g., front door, back door, windows) are considered to be more important to make sure that there is no unexpected intrusion into the house. Thus, not all the sensory data are useful (i.e., actually utilized) for the cloud to satisfy user requests, while transmitting these data (i.e., multimedia data) to the cloud will use substantial network bandwidth. From this point, we can observe that 1) sensory data that are more useful to the mobile users should be offered from WSN to cloud. On the other hand, to perform the goal of monitoring the house intelligently, the WSN needs to successfully gather and transmit the collected information (e.g., videos, images) to the cloud continuously, which means that 2) the sensory data should be reliably offered from the WSN to the cloud.

Section 2 discusses the usefulness of sensory data and reliability of WSN. WSN-MCC integration system model details are dealt in section 3. Details and design factors of TPSDT and PSS are shown in section 4. Proposed TPSDT & PSS WSN-MCC integration scheme is highlighted in section 5. Section 6 gives concusion.

2. USEFULNESS OF SENSORY DATA AND RELIABILITY OF WSN

2.1 Usefulness of sensory data

In the context of WSN-MCC integration, this paper considers the usefulness of sensory data according to whether the sensory data offered by the WSN is eventually utilized by the cloud to satisfy the data requests from mobile users.

2.1.1 User data request characteristics

The behavior that a user issues data requests to the cloud is usually characterized by Time [7]. For instance, although the traffic information of the whole city has some value to a certain extent, a lot of mobile users may be more interested in the traffic information of the downtown than the traffic information in a quiet countryside during the same time period. Meanwhile, a substantial number of mobile users may only be interested in the traffic information of a certain set of places (e.g., company, living residence, restaurant, school) among all the places in the city. In short, the transmitted data from the WSN to the cloud may not be fully utilized by the cloud to satisfy the mobile users' data requests, as mobile users generally issue data requests for some certain contents for a specific time period. Thus, it is not necessary for the WSN to always transmit all the sensory data to the cloud, since it is not efficient and it also increases the transmission bandwidth requirement and exacerbates the network traffic.

2.2 Reliability of WSN

In WSN-MCC integration, one aspect of WSN reliability relates to whether the WSN is continuously able to gather and transmit the sensory data to the cloud successfully. We observe the following critical issues concerning the reliability of WSN.

2.2.1 Depletion of sensor energy

Generally, sensors will deplete their limited battery power by performing data sensing, processing and transmission after a certain period of time, as they are often equipped with batteries that are not rechargeable and battery replacement may also be impractical [9]. Particularly, the sensors close to the gateway are serving as intermediary nodes that forward most packets to the gateway on behalf of the source nodes. Therefore they may deplete their energy sooner than other sensors and form holes in the WSN where no data can be collected for the cloud, or cause the WSN to be disconnected.

2.2.2 Failures in sensory data transmissions

The data transmissions from one sensor to another sensor and from the WSN to the cloud may encounter failures or losses, due to various factors such as network congestion, limited bandwidth or interference [8]. In such cases, if the WSN does not perform data retransmission, then the cloud cannot obtain the sensory data coming from the WSN.

3. WSN-MCC INTEGRATION SYSTEM MODEL

The WSN-MCC integration system is modeled and analyzed in this paper based on the following assumptions. There is one cloud C and M mobile users (i.e., U = (u_1, u_2,..... u_M)) as well as M WSNs (i.e., WSN = (wsn_1, wsn_2,....... wsn_M)). Each WSN gathers and transmits data to the cloud to satisfy the data requests from each corresponding mobile user.

Each WSN consists of one gateway g as well as N sensor nodes (i.e., I = (i_1, i_2,..... i_M)). Each gateway g is externally powered with an unlimited energy supply. Each sensor node i has a limited energy supply powered by a non rechargeable and non-replaceable battery, which has an initial energy $e_0$and a residual energy e_i. Time is divided into Z time periods (i.e., T = (t_1, t_2,..... t_Z)).

4. TPSDT AND PSS

In this section, we present and discuss the proposed 1) TPSDT mechanism for WSN gateway to selectively transmit sensory data that are more useful to the cloud and 2) PSS mechanism for WSN to save energy consumption so that it can gather and transmit data in a more reliable way.

4.1 TPSDT

The difference between our proposed TPSDT and other selective data transmission method (e.g., [10]) in WSN is that TPSDT is the first method for WSN gateway to selectively transmit data to the cloud, considering the time and priority characteristics of the data requested by the mobile user. These characteristics are recorded in **Point vs Time & Priority (PTP)** table maintained in the cloud for each mobile user, where each point corresponds to a sensor node and the time reflects the specific time period and the priority reflects the probability that the mobile user requests data from the corresponding sensor node during that time period.

4.1.1 PTP table

Based on the time and priority features illustrated in Section 2 about mobile user data requests, we consider that the cloud is able to analyze the historical behaviors of mobile user data requests and then maintain a PTP table of each mobile user with respect to time and priority for sensor nodes of interest.

An example of this PTP table reflecting the interest of a mobile user is shown in Table1. Specifically, the probability that the data requests correspond to each point of interest, as shown in the PTP table, represents the priority of the requested data to the mobile user. A higher probability connected to a given point in a specific time period means that the mobile user is more interested in that point and is more likely to issue data requests for the point in that specific time period.

Assume the number of data requests issued for a point of interest (e.g., sensor node i) during each specific time period t in the history is r_i^t . In addition, given that the number of data requests issued to all points for each specific time period t in the history is R^t. The probability (i.e. p_i^t) that the data requests concern the sensor node i in each specific time period t is calculated as follows.

$$p_i^t = \frac{r_i^t}{R^t} \quad \text{.....(1)}$$

In addition, for the whole WSN-MCC integration, there are Z time periods and N sensor nodes.

$$1 = \sum_{i=i_1}^{i=i_N} p_i^t \,(t = t_1, t_2, \dots t_Z) \quad \text{....(2)}$$

Thus, This PTP table obtained for each mobile user is updated dynamically by the cloud C and sent to the gateway g of each corresponding WSN.

TABLE 1
Example of Point vs Time and Priority (PTP) table

Point of Intrest	9:00am-10:00am	10:00am-11:00am	11:00am-12:00pm	12:00pm-1:00pm
i1	10%	5%	20%	15%
i2	20%	5%	0%	15%
i3	20%	10%	0%	15%
i4	10%	10%	0%	10%
i5	20%	20%	0%	15%
i6	10%	20%	30%	15%
i7	5%	20%	40%	5%
i8	0%	5%	0%	5%
…	…	…	…	...

4.1.2 Details of TPSDT

With the PTP table, the process of our proposed TPSDT for each WSN gateway to selectively transmit data that are more useful to the cloud is shown as follows.

1) Each gateway g sets a timer, which records the current time.

2) For each time period t, each gateway g sends the sensory data to the cloud C, according to the start time and end time of t in the PTP table.

3) Particularly, for the transmitted data content, each gateway g sends the sensory data gathered by each sensor node in order, according to the priorities (i.e., probabilities in the PTP table). The sensory data gathered by the points of interest with larger priorities are sent first, followed with sensory data collected by those with lower priorities. The sensory data coming from the points of interest with no priority (i.e., probability is 0%) in the PTP table are not transmitted.

4.2 PSS

The difference between our proposed PSS and other sleep scheduling algorithms (e.g., [11]) in WSN is that PSS first incorporates the time and priority characteristics of the data requested by the mobile user into the WSN sleep scheduling process to gather and transmit data for the cloud, with PTP table.

4.2.1 Design factors

The design of the proposed PSS algorithm considers the following three factors:

1) the points of interest (i.e., sensor nodes of interest in WSN) in the PTP table with probability larger than 0% should be awake in each time period t, since mobile user requires sensory data gathered by these sensor nodes;

2) The whole sleep scheduled network should be connected so that data transmissions from sensor nodes to gateway can be performed;

3) only a subset of all sensor nodes should be awake in each time period t to reduce energy consumption - the sensor nodes that are scheduled to be awake should generally have more residual energy than the nodes that are scheduled to be asleep, so that network lifetime could be further prolonged.

4.2.2 Details of PSS

Considering the above three design factors, the pseudo code of the proposed PSS algorithm is shown as follows.

Pseudo code of PSS algorithm

First: Run the following at gateway g during each time period t

Step 1: Gateway g obtains PTP table.

Step 2: If p_i^t>0, g sends flag A to node i.

Step 3: Run the second part at each node i.

Second: Run the following at each node i during each time period t.

Step 1: Get the current residual energy rank e_i.

Step 2: Broadcast e_i and receive the energy ranks of its currently awake neighbors N_i. Let E_i be the set of these ranks.

Step 3: Broadcast E_i and receive E_j from each j $\in N_i$.

Step 4: If $|N_i|$ < k or $|N_j|$ < k for any j $\in$ N_i, remain awake. Go to Step 7.

Step 5: Compute C_i = {j| j $\in$ N_i and $e_j > e_i$}

Step 6: Go to sleep if both the following conditions hold. Remain awake otherwise.

- Any two nodes in C_i are connected either directly themselves or indirectly through nodes within i's 2-hop neighborhood that have e_j more than e_i.
- Any node in Ni has at least k neighbors from C_i.
- It does not receive flag A.

Step 7: Return.

5. PROPOSED TPSDT & PSS WSN-MCC INTEGRATION SCHEME

5.1 Overview

Fig. 2 shows the proposed TPSS scheme to gather and transmit sensory data for WSN-MCC integration, towards reliably offering data which are more useful to the mobile users from WSN to cloud. The detailed steps of TPSS for each WSN to gather and transmit sensory data for each corresponding mobile user are depicted as follows.

1) Sensor nodes determine their awake and asleep states with PSS.

2) Sensor nodes sense the environmental data with a set frequency and store the sensory data as well as process the sensory data.

3) Sensor nodes send the processed sensory data to the gateway g with the many to one and hop by hop pattern.

4) Gateway g stores the received sensory data and then processes the sensory data.

5) Gateway g selectively transmits the sensory data to the cloud C with TPSDT.

6) Cloud C further stores and processes the received sensory data.

7) If data transmission from i to g or g to C experiences data losses or failures, i or g performs data retransmission until the data transmission is successful.

8) Mobile user u issues data requests to cloud C and cloud C transmits the requested sensory data to the mobile user u.

9) If data transmission from C to u encounters data losses or failures, C performs data retransmission until the data transmission is successful.

10) Cloud C dynamically updates the PTP table with equation (1) if the time and priority features of the requested data of the mobile user are changed and sends the updated PTP table to gateway in each time period t.

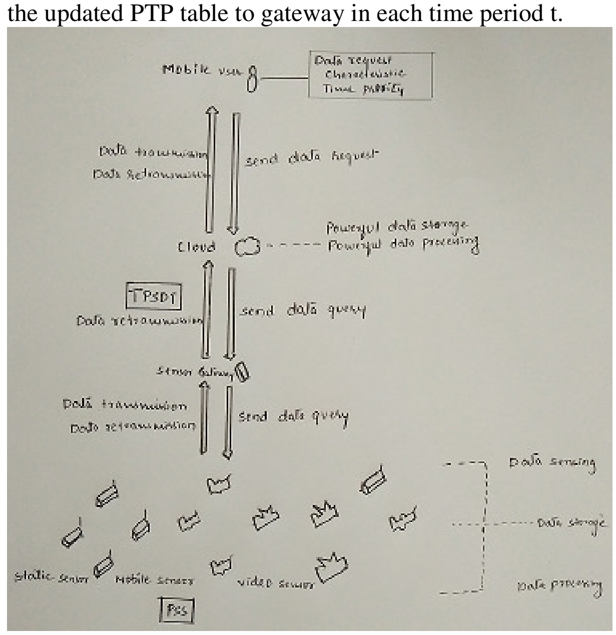

FIG 2: Proposed TPSS scheme to gather and transmit sensory data for WSN-MCC integration

6.CONCLUSION

In this paper, we have focused on WSN-MCC integration by incorporating the ubiquitous data gathering ability of WSN and the powerful data storage and data processing capabilities of MCC. Particularly, to support WSN-MCC integration applications that need more useful data offered reliably from the WSN to the cloud, we have identified the critical issues that impede the usefulness of sensory data and reliability of WSN, and proposed a novel WSN-MCC integration scheme named TPSS to address some of these issues. Specifically, TPSS consists of the following two main parts: 1) TPSDT for WSN gateway to selectively transmit sensory data that are more useful to the cloud, considering the time and priority features of the data requested by the mobile user; 2) PSS algorithm for WSN to save energy consumption so that it can gather and transmit data more reliably.

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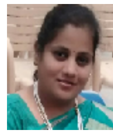

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