Low Latency and Energy Efficient Sensor Selection for IoT Services

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***Abstract*—Internet of Things (IoT) is an anytime-anywhere networking technique to connect the smart objects irrespective of their location. The growing world of IoT is accompanied with a growth in the number of associated sensors, growing at a much faster rate. So, the role of choosing appropriate sensors to synchronize with the IoT services in different applications becomes a big challenge owing to the heterogeneity, diversity and huge number of sensors, different user requirements and preferences, specialized criteria needs for various process, etc. So, the task of sensor selection by the middleware becomes very cumbersome as well as vital. This paper presents a collocation based sensor-service mapping strategy that has been used to link the IoT services to the most suited sensor device. The aim is to reduce the latency incurred in collecting the sensed data. It also considers the energy requirements of the system so that the system has a prolonged lifetime. A comparison has been done with previously existing collocation based distance algorithm that involved mapping based on reducing the overall energy of the system and random mapping where services are randomly allocated to any device. The comparison shows results in favor of the proposed algorithm.**

Keywords*—*Internet of Things, Latency Minimization, Energy Saving, Energy Balancing, Service Mapping

I. Introduction

IoT is expanding into different domains of our lives like home automation, smart cities, smart agriculture and environment, health and fitness, supply chain and logistics, entertainment and social life, energy conservation, etc. [1]. One of the main factors contributing to its expansion is the growing number of sensors. IoT seems to be improving different areas with the help of these small, powerful sensors that capture the data around and serve as the key for collecting information. The IoT sensor market has about 42.08% Compound Annual Growth Rate and by 2022, it is expected that the market will reach USD 38.41 Billion [2]. Different factors have contributed to the growth like development of sensors that are much smaller, smarter and cheaper, market growth for smart devices, real time computation needs, etc [2] which show the extent of its importance and varied use in this ever growing network.

On one hand the sensors provide an opportunity for multiple use cases according to the requirements of user and needs of the application but on the other hand, the large number and heterogeneity poses a great challenge for choosing the most suitable sensor(s) that can serve best in the scenario. The problem of sensor selection by optimizing a utility function for application has been shown as NP-hard [3] due to the large solution domain. So it is essential that efficient mechanism is applied to select the most suited sensor for the application from the huge number of different sensors present.

IoT faces many challenges but three issues pose a prime concern especially when we have entered into the phase of smart cities and smart devices. These challenges include the exponential growth in amount of data generated, security and privacy issues and latency [4]. Of these three concerns, latency becomes a very challenging issue as we are dealing with huge data volumes and the acceptable response time is very short and the users expectation of quicker response has been rising, especially in the last few years [5]. Thus, the response has to be generated very fast especially if dealing with real time services. Thus, it becomes very essential to choose such sensors that help in reducing the latency incurred.

This paper applies a collocation based sensor selection process that seeks to minimize the latency caused in collecting the sensed data for IoT applications as reduced latency is always a desired characteristic of IoT and has a significant impact in applications where shorter deadlines have to be met. The contributions of the work done are as follows. A greedy approach for mapping components to appropriate sensors of an IoT system modelled in a household scenario has been presented that aims to minimize delay caused in servicing users request by minimizing the latency occurred in transferring the sensed data and communicating it to the gateways. Energy being the most critical resource of the IoT system has also been taken into consideration to increase the system lifetime [6]. The mapping strategy gives positive results towards reducing latency and energy consumption of IoT system.

The rest of the paper has been organized in different sections. Section 2 mentions the related work in a brief manner. The System Model has been explained in section 3 with the related system description, undertaken constraints, used methodology and the problem definition. The mapping technique and its associated algorithm have been discussed in section 4. Section 5 shows the different performance parameters for the process. The results and findings of the work have been given in section 6 while section 7 includes the conclusion of the entire work.

II. Related Work

Masayuki Hirayama [7] discusses a step by step process to be carried out for sensor selection in an embedded system. It states a sensor selection should be preceded by target identification, viewpoint analysis, checking physics of sensor, categorizing sensing level in presence-judging, scale-measure or physical degree sensor, checking conditions and constraints and identifying potential sensors. These may work as preliminary steps to be carried out in a sensor selection procedure to identify the candidate sensors for further application of the selection algorithms.

Z. Huang et al. [8] have proposed a simple greedy algorithm for sensor selection that serves two different objectives of minimizing the energy consumption during the entire communication and balancing the energy amongst all the devices present, in order to increase the system lifetime. It intakes flow of the entire process as input and has a prior information of devices capability of running different services and then decides the mapping for these services in appropriate devices. It uses a strategy to collocate different components on a link to the same device so as the communication cost for the link can be avoided and thus result in a reduction in the overall energy cost. It further maps components that have not been collocated to devices using an Integer Linear Programming(ILP) in such a way the energy remains balanced on all sensor devices.

Z. Huang et al. [9] further improved the energy formula by considering the communication distance between the devices forming the link as [8] was distance ignorant and two devices close to each other are assumed to consume same energy as two devices far away from each other. In this when two or more collocations were possible; it was done on the link with maximum distance. Similarly, to map the other services that were not collocated they were mapped in such a way so as to minimize the distance between the sensors. This, in turn saved the maximum possible communication energy.

Researchers demonstrate how collocation based sensor selection strategy helps in reducing the overall energy consumption of the IoT system [8], [9]. Adding the energy constraint on each device balances the energy on each of the devices thereby increasing the systems lifetime. But none of the two address the prime concern of latency which will be one of the most deciding factors in the success of IoT. Fergal Toomey [5] tells how user psychology is changing and is ready to accept only the faster applications that give quicker response. Researchers demonstrate a QoS based service composition [10], [11] and a QoS aware sensor selection technique [12] when it deals with service oriented computing.

This motivates to employ a sensor selection technique for IoT services which leads to reduced latency and also takes into account the energy consumption of the system which is a very crucial resource to keep the IoT system running and functioning for long.

III. System Model

The work is associated with finding the required mapping of IoT components onto the appropriate sensor device within an IoT system deployed in a particular environment.

A. *System Description*

The system is based on a device to gateway connectivity model that includes various entities like gateways, landmarks, sensor devices, Flow Based Process(FBP) that has to be carried out and cloud responsible for storage and processing of the data if required.

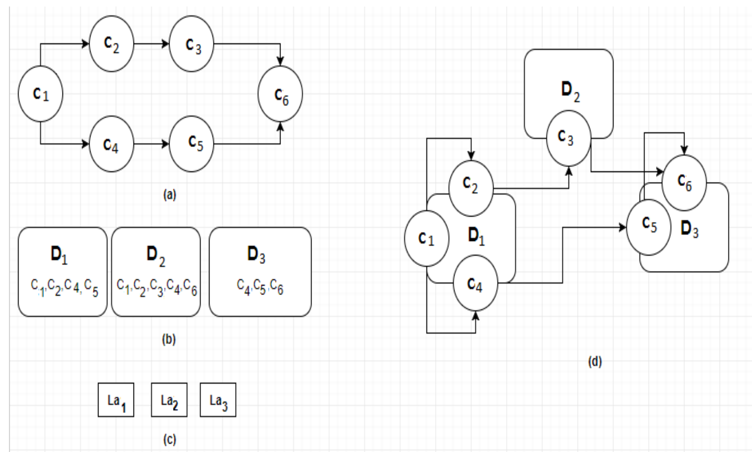

Fig. 1: Sample FBP Mapping

The gateway is the monitoring and controlling entity responsible for taking the mapping decisions of allocating the components on the appropriate devices after working out the algorithm and thus deciding the path of flow of data through the devices and finally collecting it for processing. A set of s landmarks La=$\{La_1,La_2,..,La_s\}$ also forms part of the system to filter devices for hosting components. The set of n sensor devices D=$\{D_1,D_2,..,D_n\}$ with multiple heterogeneous sensors responsible for sensing the physical environment are capable of hosting multiple components where one component may be hosted on more than one device. The FBP represents the flow of information between different components as desired by the user for the scenario. FBP F(C,L) is a Directed Acyclic Graph(DAG) that can be described as set of links L connecting a set of m components C=$\{C_1,C_2,..,C_m\}$ where each link L_{ij} represents the link between pair of components (C_i,C_j) with an associated data volume. Fig.1 shows a sample FBP Mapping where (a) represents an FBP showing a sample flow of components, (b) shows the devices present in the system with the list of components it can host, (c) shows the different landmarks present in the system and (d) shows the final mapping of component services on different devices.

B. *Methodology*

The delay $l_{L_{ij}}$ for transferring data on link L_{ij} is computed as [13]:

$$l_{L_{ij}} = \gamma_{ij} + \mu_{ij} + \xi_{ij} + q_{ij} \tag{1}$$

where γ_{ij} denotes the transmission time, μ_{ij} denotes the propagation time, ξ_{ij} denotes the processing delay and q_{ij} represents the queueing time.

The transmission time and propagation time for link L_{ij} are calculated as :

$$\gamma_{ij} = \delta / k_{ij} \tag{2}$$

$$\mu_{ij} = d_{st} / \nu \tag{3}$$

where δ denotes the size of data packet, k_{ij} denotes the bit rate for the link, d_{st} denotes the distance between the devices D_s and D_t on which the components C_i, C_j are to be hosted respectively and ν denotes the propagation speed.

The total latency for the entire process i.e communicating the data to complete the flow of process is given as the sum of latency over each link.

The transmitting energy cost $E_{Tr}$and receiving energy cost E_{Re} for k bits of data is given as :

$$E_{Tr} = E_{ele} * k + \varepsilon_{amp} * k * d^2 \tag{4}$$

$$E_{\mathrm{Re}} = E_{ele} * k \tag{5}$$

where E_{ele} gives the radio electronics parameter and ϵ_{amp} is the amplification parameter and d is the distance between the two devices on which two components forming the link are hosted.

The energy cost $E(C_i)$ for a component is described as the sum of transmission energy of all the outgoing remote links L_{is} and receiving energy of all incoming links L_{qi} given in following formula :

$$E(C_i) = \sum_s E_{Tr_s} + \sum_t E_{Re_t} \tag{6}$$

The energy status of each device is collected regularly during the process using the following formula whenever a service is allocated to any device.

$$E(D_m) = \sum_i (x_{im} * E(C_i)) \tag{7}$$

where the variable x_{im} is a binary variable that takes the following values

$$x_{im} = \begin{cases} 1, & if\ C_i\ is\ mapped\ to\ device\ D_m \\ 0, & otherwise \end{cases} \tag{8}$$

The latency incurred on each link adds to the overall latency due to transmission of data across devices. But if both the components are mapped on same device capable of hosting them then the latency becomes zero for the link as there is no transfer of data across the devices. This results in a decrease in the overall latency as only processing delay is counted. Also the communication energy cost becomes zero if both services are hosted on same device. So the collocation decreases both latency as well as energy cost for all the links collocated on the same device.

C. *Constraints*

1) **Location Constraint**
This is a user defined constraint to fix the distance between certain landmarks and the device on which its corresponding service is hosted so that the devices not meeting the criteria are filtered out during collocation. The distance constraint $Dist_{ij}$ between device D_m that hosts component C_i and landmark La_j for set of components S_C is applied as follows :

$$x_{im} * d(m,j) \leq Dist_{ij}, \quad \forall C_i \in S_C \tag{9}$$

where *d(m,j)* is the actual distance between device D_m that hosts component C_i and landmark La_j

2) **Energy Constraint**
Using energy harvesting technologies prolongs the lifetime of the system but within a certain time duration, only a limited energy can be obtained. So, the users are free to set a constraint on devices regarding the maximum consumption of energy by the services as after a certain limit the device may no longer be able to accommodate any more components and if done the system may not be able to continue working for a long duration. The energy constraint E_m for set of devices S_D is applied as follows :

$$E(D_m) \leq E_m, \quad \forall D_m \in S_D \tag{10}$$

D. *Problem Definition*

The problem deals with finding correct device for m services from a set of n devices to meet certain objectives working under some constraints.The process aims to decide a mapping for FBP components on the system devices with the three objective functions for optimization to carry out following objectives (a)to minimize the overall latency incurred in the process **min**($\sum l_{L_{ij}}$), (b)to minimize the overall energy cost of the system **min**($\sum E(D_m)$), and (c) balancing the energy on different devices in the system **min**(**max**($E(D_m)$)).

IV. Algorithm

The process involves mapping components on the appropriate device with an objective of reducing the overall latency and energy consumption. The process is divided in two parts, the first is to find a path that leads to minimized latency. Algorithm 1 describes the process for finding minimum delay path. Here, for each link it involves choosing the pair of devices for hosting the link components such that latency incurred is minimum out of all the possibilities after which a temporary mapping is done that is used for the next step that involves collocation of the links.

Algorithm 1: *Select – Path*

Input: List of devices D hosting services and the FBP F(C,L)

Result: Minimum delay path.

for *each link L_{ij} in the FBP* **do**
    for *each pair of device that can host the services at link ends* **do**
        if *the sending device of current link is same as receiving device of previous link* **then**
            Compute latency for sending the data across link using the two devices.
        end
    end
    Choose the computed minimum latency device pair of current link for the path such that the receiving device of current link can host sending service of next link(if exists).
end

Algorithm 2: *Latency Based Service Collocation*

Input: List of devices D hosting services and the FBP F(C,L)

Result: Service mapping after collocation

MP= ϕ Compute the latency based initial path of devices MP' for allocating the services using Select-Path algorithm.
Designate all links L_{ij} as remote and form a queue Qu_L of links in decreasing order of latency from the selected path.
Form a queue Qu_D of all devices in increasing order of the current energy cost
while *Qu_L is non-empty* **do**
    Choose the link L_{ij} with largest latency value
    if *L_{ij} is remote, and MP(i) $\notin$ MP and MP(j)* **then**
        if *DV=$\{D_k|$ C_i and C_j can be hosted on $D_k\}$* **then**
            if *MP'(i) $\in DV or MP'(j) \in DV$* **then**
                Select as D_k and choose one with lower energy if can be collocated on both
            end
            else
                Select D_k with lowest energy that can host both the services
            end
            Add MP(i)=k and MP(j)=k to MP
            Update the device energy cost of D_k
            Mark L_{ij} as local
        end
    end
    else
        if *L_{ij} is remote, $\exists$k,MP(i)=k or MP(j)=k* **then**
            if *C_i and C_j can be collocated on $D_k\}$* **then**
                Add MP(i)=k and MP(j)=k to MP
                Update the device energy cost of D_k
                Mark L_{ij} as local
            end
        end
    end
    Remove L_{ij} from Qu_L
end

In Algorithm 2 the collocation strategy has been described where the components forming a link are collocated on the same device so as the latency incurred on transmitting the data on the link is reduced. The collocation is done on links in order of decreasing latency. It checks whether the components can be collocated on one of the two devices for the link in the initial temporary map. If collocation is possible on both devices then it is collocated on the device with minimum energy. If it cannot be collocated on any of the devices then it is checked if the collocation can be carried out on any other device.

V. Performance Metrics

1) **Service Latency Ratio(SL-Ratio)**
It is the ratio of latency incurred by the technique to maximum latency incurred amongst all techniques for the same FBP.

2) **Total Cost Energy Ratio(T-Ratio)**
It gives the ratio of energy cost of the entire FBP by the technique to the maximum energy cost given amongst all techniques for the same FBP.

3) **Largest Energy Cost Ratio(L-Ratio)** It defines the ratio of highest energy cost of any device by the technique to the maximum device energy for the same FBP amongst all techniques.

VI. Simulation and Results

The simulation has been carried out in MATLAB R2017b on Intel(R) Core(TM) i3-5005U CPU @ 2.00 GHz(4CPUs) and 4GB RAM with parameters set as following. The MATLAB Simulator has been widely used to evaluate various advanced proposed techniques in the literature [14], [15] . The processing speed has been set to $2*10^6$ m/sec and the packet size has been fixed to 1526 bytes. The processing delay has been kept to 0.025 ms. The queueing time is assumed negligible. The radio electronics parameter is taken 50 nJ/bit and the amplifier parameter is taken to be 10pJ/bit/m^2. The number of components have been taken between 10 and 100. The number of devices has been kept about 50% - 70% of the number of components with each device capable of hosting 3 to 5 different IoT services. The process has been tested with multiple,different graphs giving linear, star and random FBP and the average of ratio values over multiple simulations has been shown in the result.

Results have been shown for the three techniques applied in different types of FBP. Fig.2 demonstrates their comparison for linear FBP. Random Mapping strategy involves mapping the services randomly on any device that is capable of hosting it, results in reduction in maximum device energy in some cases as services are allocated to random devices but reduction in latency as well as overall energy consumption is very low. The distance algorithm proposed in [9] apart from reducing energy also results in latency reduction for the FBP after applying the collocation strategy but the proposed algorithm provides better results for all three parameters in comparison to the other two techniques. Same pattern is observed for star and random FBP

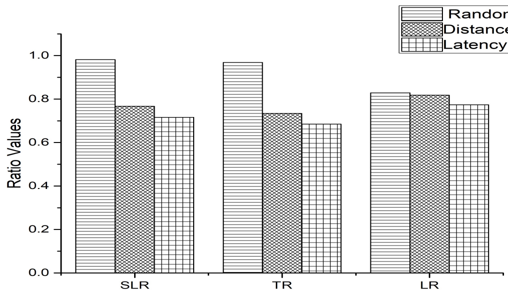

Fig. 2: Comparison for linear FBP

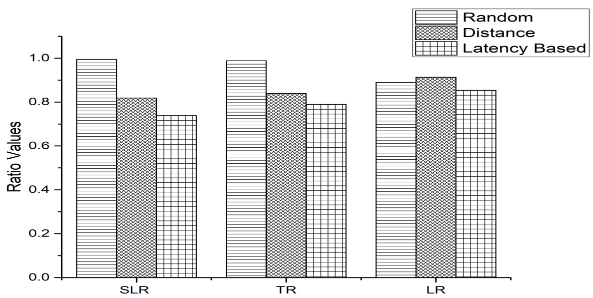

Fig. 3: Comparison for star FBP

as shown in fig. 3 and fig. 4 respectively.

VII. Conclusion

This paper presents a greedy collocation based strategy to host IoT services in appropriate device in a smart home scenario such that the latency and energy both are taken care of since latency plays an important role in sending quicker response, meeting the shorter deadlines and energy is the most crucial factor when comes to giving uninterrupted IoT services for long time. Our results show that the latency based collocation strategy for mapping IoT services to sensor devices in comparison to other techniques gives more reduction in both latency and energy consumption and balances energy across devices, though the reduction totally depends on the possibility of collocation and the difference in distances between different device pairs.

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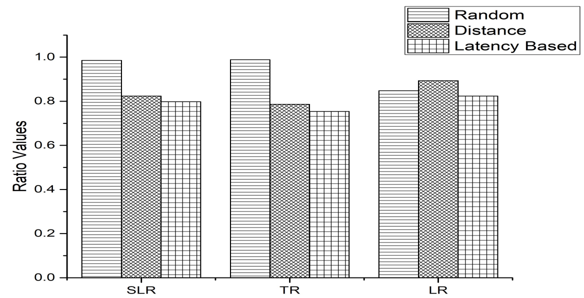

Fig. 4: Comparison for random FBP

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