A Fog based System Model for Cooperative IoT Node Pairing using Matching Theory

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Abstract—The revolutionized vision of IoT has united heterogeneous devices to foster the systems of cohesive intelligent things. In addition, Fog computing has also envisioned a new form of cloud computing paradigm. Therefore, Fog provides edge computing to such IoT devices with varied capabilities and resources. However, a balanced and efficient pairing or matching strategy for edge IoT nodes is crucial to achieve the user requisite. Hence, this paper addresses the utility based matching or pairing problem within the same domain of IoT nodes by using Irving's matching algorithm under the node specified preferences to endure a stable IoT node pairing. We studied the performance of the proposed matching algorithm through simulation. The simulation results show the higher utility gain of the node pairs through refined matching algorithm over greedy approach.

Keywords—Fog computing, Internet of Things(IoT), Peer-to-Peer(P2P), Matching game

I. Introduction

The envisaged notion of IoT endorses different heterogeneous intelligent devices with a diverse range of characteristics like Automation, Intelligence, Dynamicity, and Zero-Configuration [7]. A recent study [6] by Gartner predicts that, by the year of 2020 around 26 billion of IoT units will be connected to the network which will contribute immensely in the global economy by opening a diverse market of 1.9 trillion USD. As a matter of fact,these devices will require a significant amount of both network and physical resources in order to perform different context aware tasks in real time. As a result, defining an efficient resource allocation scheme should be considered as the future challenges in IoT along with the current challenges like Heterogeneity, Scalability, Interoperability, and Security and Privacy [8].

In recent years, to provide a better quality of service(QoS) to the end devices, the cloud computing paradigm has shifted towards the edge of the network. Hence, the emergence of Fog enables a highly virtualized computing platform that provides data processing, storage and network service like cloud [10] . The generic advantages of Fog over cloud computing in case of IoT is that Fog provides low latency and location awareness, mobility, various wireless communication capability and heterogeneity to different mobile IoT devices. Thus, the concept of Fog enables edge computing to different heterogeneous

Fog devices or in other words IoT devices to ensure better QoS than its predecessor cloud. In reality, nowadays mobile or IoT devices are not quite considered as resource constrained devices since the devices are often equipped with reasonable processing power, memory, energy and storage to cache decent portion of user data. In fact, a Fog environment is highly being dense with Fog devices where these are capable of providing short range device to device connectivity unlike the traditional concept of resource constrained mobile devices. Despite the ongoing efforts to provide edge computing to the IoT devices, an efficient and cooperative utility based pairing strategy between the high-end IoT nodes to share resource efficiently still lags to utilize the full potential of such devices. So, the main contribution of this paper is: to provide an efficient IoT node pairing scheme between the same domain of IoT nodes in Fog paradigm. In order to achieve this goal, we refine the Irving's matching algorithm and model the problem as an *one sided stable matching game* with quota. To support such kind of matching game, we also define the utility based preference list for all IoT nodes pairing.

II. Related Work

Interoperability is a key feature in IoT where heterogeneous objects have the ability to inter-operate dynamically with less human intervention. Therefore, the IoT objects can also share and allocate resources among themselves in order to perform necessary sensing and actuation tasks. In [1] the authors proposed a distributed optimization protocol derived from a consensus algorithm for resource allocation and management in IoT. The authors have considered the dynamic nature of an IoT network topology in terms of task frequency and buffer storage. Their proposed solution can fulfill the resource allocation requirement of homogeneous IoT nodes which is also vigorous against any node failure during runtime.

In cloud computing paradigm, VM migration problem is considered as one of core challenging research issue which requires for efficient and practical solutions. In [2] the authors have used a generic framework based on stable matching concept to solve the VM allocation to servers problem. Unlike the utility based optimization solution, the authors have solved the VM migration problem by using deferred acceptance procedure. In order to ensure a fair VM allocation to servers, the authors have also proposed egalitarian approach to find a fair and stable matching between VMs and servers. Due to the egalitarian approach the total rank sum of the matching

outcome is minimized thus provides fairness under mild conditions.

In case of mobile gaming and multimedia applications, huge amount of network resources are required to provide the desired QoS to end user. In [3] the authors have focused on the joint uplink/downlink resource allocation for the next generation OFDMA based wireless networks. Thus,the authors have proposed a novel approach for subcarrier allocation approach which is suitable for different services that ignite joint uplink/downlink QoS requirements. The subcarrier allocation problem is modeled as a two sided matching game that corresponds to a novel resource allocation algorithm. Not to mention,an efficient and fair joint uplink/downlink subcarrier allocation plays a significant role to achieve a considerable performance gains in terms of average utility per user.

To support better QoS to the resource constrained IoT devices cyber foraging technique where the resource poor IoT devices are reluctant in terms of performing heavy computations by offloading some of their heavy work to a nearby stronger surrogate machine. In [9] the authors have focused on the pervasive usage of the mobile devices according to the user requirement of running the same computation task that they use in more powerful devices. But there is a wide disparity between the mobile devices and non-mobile devices with stronger configuration that hinders providing the QoS to end user . So, to eradicate the hindrance, the authors have used the cyber foraging techniques where non-mobile devices act as surrogate and the mobile devices can utilize these surrogate devices to run the programs that are not compatible with the traditional mobile device configuration.
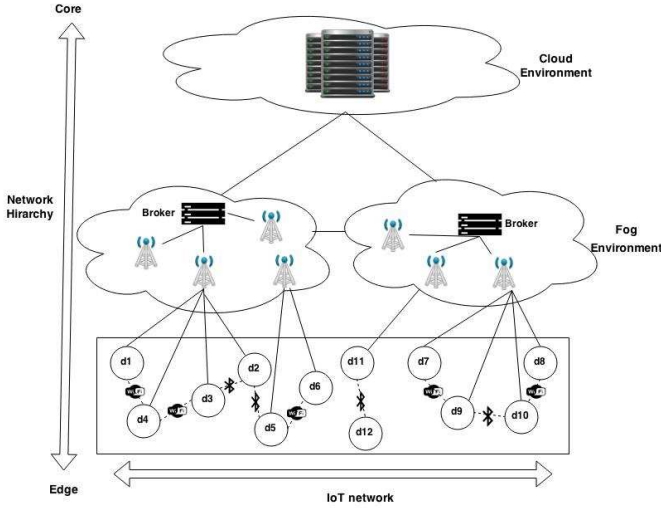
III. SYSTEM MODEL

Fig. 1. System model for Fog based IoT network

In Fig.1, the system model represents an IoT network composed of heterogeneous MIMO enabled IoT device nodes in Fog environment. In the network hierarchy, these devices are located near to the edge where Fog environment provides cloud like service to IoT devices. Moreover, different IoT nodes are connected to the Fog infrastructure,more specifically Fog access points in order to communicate with each other remotely. Each Fog can also communicate with other Fog environment in the vicinity which offers efficient service mobility for IoT. One or more broker reside in the Fog infrastructure which sets the pricing factor for the node utility function in case of devising a preference list for pairing IoT nodes under the Fog environment. The Fog devices of IoT nodes can communicate with each other through short range communication medium like WiFi-Direct or Bluetooth. Since the IoT nodes are well-equipped with a diverse range of network and physical resources, they can be paired together to share their resources among each other in a cooperative way to achieve the user specific requirement.

A. Utility Model

In this utility model, node i and j are willing to pair together in order to form a stable matching and node i wants to transmit data to node j. Since the data transmission power is directly proportional to transmission distance, based on Friss - free space model [5] the data transmission expenditure in terms of energy consumption to transmit for node i is x_i^U and to receive data for node j is x_j^D.

$$x_i^U(k,d) = n2 * k * ((E_{elec} + E_{da}) + d^\theta * E_{amp}) \quad (1)$$

$$x_j^D(k) = n_1 * k * (E_{elec} + E_{da}) \quad (2)$$

In (1) and (2), E_{elec} is the energy consumed by circuit,E_{da} is the energy consumption for data aggregation and E_{amp} is the energy consumption for amplification in order to transmit and receive k number of bit over a distance d where the path loss exponent is θ.The value of θ is usually within a range of [2,4]. The bandwidth for transmit and receive data is $n2$ and $n1$ correspondingly.

$$r_i^U(t) = \log x_i^U(k,d)/t \quad (3)$$

$$r_j^D(t) = \log x_j^D(k)/t \quad (4)$$

So, (3) and (4) represent the transmission and reception data flow rate of node i and node j correspondingly with the reception and transmission bandwidth n_1 and n_2 over a time slot t.

When node i and j intend to send or receive data to each other, the nodes have to consider the energy consumption for the transmission of k bit of data, node distance, data transmission or reception rate and the cost and benefit involved for transmission/reception with buffer occupancy.

$$x_i(k,t) = r_i^U(t) + B_i(k,t) \quad (5)$$

$$x_j(k,t) = r_j^D(t) + B_j(k,t) \quad (6)$$

In such case, (5) and (6) calculate the total data flow rate during transmission and reception with buffer occupancy $B_i(k,t)$ and $B_j(k,t)$ in time t for node i and j. The cost of node i for sending data and buffer occupancy is,

$$C_i(k,t) = x_i(k,t) * p_i + (s * k) \quad (7)$$

In (7), p_i is the price for energy consumed for k bit of data that node i has to pay to node j for data transmission whereas s is the flat rate service charge for transmitting data k.

The cost of node j for receiving data and buffer occupancy is,

$$C_j(k,t) = x_j(k,t) * p_j \qquad (8)$$

In (8), p_j is the price that node j has to pay for data reception from node i. Thus, utility in node i for k bit of data is,

$$U_i = (\gamma_i * k) - C_i(k,t) \qquad (9)$$

As well as,the utility in node j for k bit of data is,

$$U_j = (s * \gamma_j * k) - C_j(k,t) \qquad (10)$$

In (9), γ_i is the flat rate pricing factor that can be set based on number of bits transmitted and buffered to node j whereas in (10), γ_j is the flat rate pricing factor that can be set based on number of bits received and buffered from node i.

IV. IRVING'S MATCHING ALGORITHM SETUP

Let us assume that heterogeneous IoT devices or nodes reside in the same domain and have the ability to inter-operate autonomously like Peer-to-Peer(P2P) IoT [11]. Therefore, we consider the network and device resource allocation scenario where IoT nodes tend to share their own available resources between each other in Fog computing paradigm. As a result, these IoT devices can not only provide edge computing to end user but also can operate even if they lack in some of their own resources. The core concept of Irving's matching algorithm [4] is to solve the stable roommate problem in order to create a one-to-one stable matching. The proposed refinement of the Irving's algorithm can initiate a cooperative pairing or matching between one to many nodes.

A. Irving's Matching Algorithm Concept

Let's consider a set of nodes $S = d_1, d_2, d_3, d_4.....d_n$ comprised of n number of nodes. For pairing,The number of participant nodes must be an even number thus $2n$. Furthermore, the matching between nodes of set S is μ_1 and μ_2 where $\mu_1 = d_1, d_2$ and $\mu_2 = d_3, d_4$. So, the matching μ_1 and μ_2 will be the stable matching if and only if no individual node within the matching μ_1 prefers an individual node from matching μ_2 over their currently matched node.In addition, each of the nodes in S have individual set of preference list $P = p_{v_1}....$ where the nodes will map the other nodes within the set S based on their utility ratio of transmission and reception of data. If μ_1 and μ_2 are unstable, in such case matching is not feasible.

TABLE I. NODES OF SET S WITH PREFERENCE LIST AND QUOTA.

quota	node(s)	preference list
1	d_1	d_3,d_4,d_2,d_6,d_5
2	d_2	d_6,d_5,d_4,d_1,d_3
2	d_3	d_2,d_4,d_5,d_1,d_6
1	d_4	d_5,d_2,d_3,d_6,d_1
1	d_5	d_3,d_1,d_2,d_4,d_6
1	d_6	d_5,d_1,d_3,d_4,d_2

From Table I,in the first stage, from set S , d_1 proposes to it's first preference in the list d_3. In this case there are two possibilities. The first possibility is, d_3 will reject the

proposal from d_1 if d_3 already holds a better proposal than d_1. Otherwise, d_3 holds the proposal from d_1 and simultaneously rejects any poorer proposal than d_3's current proposal d_1. It can be noted that, an individual node in set S proposes to the other nodes in the order in which they appear in the individual node's preference list. When a promise of consideration is received the sequence of proposal made by the individual node stops. At the same time, any subsequent rejection causes to the individual node prompts to continue immediately with the sequence of proposals. The first stage terminates with two possible outcomes, either every node will hold a proposal or one node will be rejected by every other nodes in it's preference list. Table II represents the outcome of the first stage of Algorithm 1.

TABLE II. NODES OF SET S AFTER FIRST STAGE

quota	node(s)	preference list
1	d_1	d_4,d_2, d_6 ,d_5
2	d_2	d_6,d_5,d_4,d_1,d_3
2	d_3	d_2,d_4,d_5,d_6
1	d_4	d_5,d_2,d_3,d_6,d_1
1	d_5	d_3,d_1,d_2,d_4
1	d_6	d_1,d_3,d_4,d_2

Algorithm 1: First and Second stage of Irving's Algorithm

Input: The set of IoT nodes,$S = d_1, d_2...d_n$, number of nodes, $n \geq 1$, quota for each node i, c_i quota for node i's first preferred node j , c_j

Initialization:
$i \geq 0, j \geq 0; k \geq 0$;
Each node d_i sets a ranked preference profile list of other nodes d_j
Each $i, j \in S$
while *there are unpaired node* **do**
   Stage 1:
   let d_i be first unpaired node;
   d_i proposes to the first node d_j in its preference profile list which has not rejected d_i;
   if d_j *had not received no proposal* **then**
      d_j accepts d_i;
      rejects symmetrically (d_k,d_j);
      if d_j *prefers d_i over its current pair node d_k* **then**
         d_j accepts d_i;
         rejects symmetrically (d_k,d_j);
      end
   else
      reject symmetrically (d_j,d_i);
   end
   Stage 2:
   for *all d_j holding proposal from d_i* **do**
      reject symmetrically all (d_j,d_k) where d_j prefers d_i over d_k;
   end
end

The second stage starts with the outcomes in Table II. This stage performs rotation elimination and provides a set of reduced preference lists and a particular all-or-nothing cycle. As every node in the set holds a unique proposal already from

stage 1 and 2 in Table II, still any node in their preference list who prefers less than their current proposed pair is removed. For example, d_1 is currently holding the proposal of d_6 and thus removes d_5 in it's list. A stable table can be found after this stage and if not, the algorithm continues towards third stage. Table III is the representation of the outcomes of second stage of Algorithm 1. The third stage involves checking for

TABLE III.   NODES OF SET S AFTER SECOND STAGE

quota	node(s)	preference list
1	d_1	d_4,d_2, d_6
2	d_2	d_6,d_5,d_4,d_1,d_3
2	d_3	d_2,d_4,d_5
1	d_4	d_5,d_2,d_3,d_6,d_1
1	d_5	d_3,d_1,d_2,d_4
1	d_6	d_1,d_3,d_4,d_2

preference list size which is greater than one and also looks for cycle. If there is a cycle between nodes, reduction is to be applied to break the cycle to form a stable pairing. In order to find the cycle, two arrays p and q are introduced and the main task of these arrays is to spot repetition within array p which indicates the cycle. Since d_1 has more than one node in it's preference list, in this algorithm $p[0]$ is d_1 and $q[0]$ is node d_1's second preference d_2. Afterwards, $p[1]$ is the last node of $q[0]$'s current list which is d_3. The mapping sequence will follow until there is a repetition of nodes in array p. The algorithm initializes the reduction by setting $p[i], q[i] = 0$. To remove the cycle in $p[i]$, $q[i]$ rejects the proposal from $p[i + 1]$ and vice versa. Sometimes multiple cycles can appear and in such case this stage should be initiated multiple times. If after removing cycles, any preference list becomes empty,there exists no stable pairing. Table IV is the final outcome of Irving's matching algorithm.

TABLE IV.   NODE PAIRING AFTER THIRD STAGE

quota	node(s)	preference list
1	d_1	d_6
2	d_2	d_5
2	d_3	d_4
1	d_4	d_3
1	d_5	d_2
1	d_6	d_1

TABLE V.   FINAL OUTCOME OF REFINED IRVING'S ALGORITHM

quota	node(s)	preference list
1	d_1	d_6
2	d_2	d_5,d_3
2	d_3	d_4,d_2
1	d_4	d_3
1	d_5	d_2
1	d_6	d_1

B. Refined Irving's algorithm for IoT node pairing

In table IV, there is an one-to-one stable pairing between nodes in the same set S. Although the pairing is stable and produces a stable table, some of the nodes still have quota left to pair with some other nodes in the set S. For example node d_2 and d_3 each can support two stable pairing but both have one quota left even though these nodes are paired with d_5 and d_4 subsequently. The objective of refining the Irving's matching algorithm is to support quota based pairing of nodes

where each node can support both one-to-one and one-to-many pairing. In this stage, the nodes with quota left to support a one-to-many pairing can propose each other to accept or reject mutually as per lemma 1. The algorithm terminates until every node has fulfilled it's quota. The Algorithm 2 proposes the refinement of Irving's matching algorithm and Table V depicts the final outcome.

Algorithm 2: Refined Irving's algorithm for IoT nodes pairing

Input: The set of IoT nodes,$S = d_1, d_2...d_n$, number of nodes, $n \geq 1$, quota for each node i, c_i, quota for node i's first preferred node j , c_j, arrays p,q

Result: Stable pair of nodes with no quota left

while *there are nodes with quota left* **do**
    Stage 3:
    for *all cycle in $p_1,...,p_i$ and $q_1,...,q_i$* **do**
        q_i is second preference of p_i and $p_i + 1$ is the last preference of q_i;
        for $i = 1...n - 1$ **do**
            reject symmetrically($q_i,p_i + 1$);
            for *loops through the arrays p and q* **do**
                accept symmetrically(q_i,p_i);
                $c_i + +$;
            end
        end
    end
    Stage 4:
    while *nodes d_i have remained quota* **do**
        let d_i is the first node with quota, $c_i > 0$;
        d_i proposes the first rejected node d_j in Stage 2 and Stage 3 after its current pair;
        if *d_j have no remaining quota to paired with d_i* **then**
            reject symmetrically(d_j, d_i);
        else
            accept symmetrically(d_j, d_i);
            $c_i + +$;
            $c_j + +$;
        end
    end
end

Lemma 1. *If x and y rejects each other symmetrically, in stage 4, y and x can be partners if y and x have available quota to support each other in creating a separate pair along with their current partners in which both x and y have proposed and accepted each other mutually.*

Proof. Suppose that y and x are two entities in the same set S with quota size more than one. Denote μ_1 and μ_2 as a stable one-to-one pair of y and x subsequently. In case of y , y must have rejected x because of higher preferred partner, say z over x. Thus y have created a stable pair $\mu_2(y, z)$ by rejecting less preferred x in y's preference list . For x, the situation is same as y. But each of x and y can form one more stable pair besides their current pairs μ_1 and μ_2. Since for a stable pairing, both x and y have to accept or reject

each other proposal symmetrically, in stage 4 both y and x can propose to the entities which are less preferred than their current partners and can form a separate one-to-one pairing $\mu_3(y, x)$ to fulfill their quota.

V. SIMULATION RESULT AND ANALYSIS

For the simulation, we consider a target range of 50 meters and within that range there are $N = 20$ IoT nodes which are randomly located. We also consider these nodes are able to establish device-to-device communication using WiFi-Direct. The transmission and reception speed for device-to-device communication through WiFi-Direct which are set randomly up to 20 Mbps and 30 Mbps respectively. In addition, the transmission and reception rate in case of using wireless access point is 0.75 Mbps and 4.2 Mbps. The distance between the nearest WiFi access point and nodes is roughly 103 meters. The IoT nodes communicate with each other for $t = 10$ seconds and the communication terminates after this time slot . The data path loss value over a distance d is set to $\theta = 2$. The data packet size k is set to 2000 bit. We consider the amount of energy that is required to transmit and receive data from each node to other node is E_{elec} = 50*0.000000001 . The data aggregated energy and amplification energy for each node is E_{da} = 5*0.000000001 and E_{amp} = 0.0013*0.000000000001.
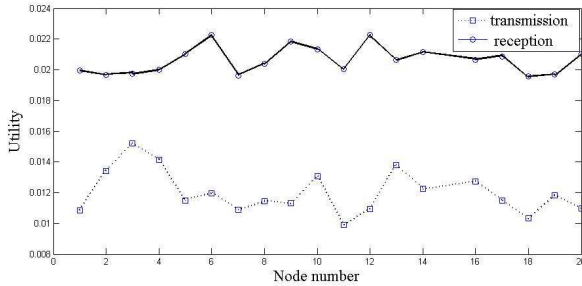

Fig. 2.   Example result showing the utility of per node transmission and reception

Fig. 2 shows the utility of 20 nodes for within the range of WiFi-Direct communication in terms of transmission and reception of data. These utilities are used to create a preference list for pairing the IoT nodes where the nodes set their individual preference list based on the utility ratio between reception and transmission. The figure also depicts the efficiency of the proposed system model in case of transmitting and receiving data to WiFi access point.

Fig. 3 shows the utility ratio of each node for transmission and reception of data from the pairing nodes. In case of nodes to transmit and receive data to/from WiFi access point the utility ratio become lower than the node-to-node data pairs which reside in the vicinity of each other. The results in Fig. 3 illustrates the discrepancy between the utility ratio of node-to-node communication over a short distance communication and node-to-acces point communication. Since the nodes have to spend more network resources and physical resources such as energy to transmit and receive data from access points, the cost for communication gets higher and the utility ratio becomes
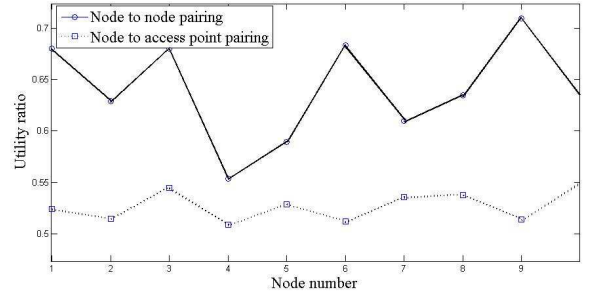

Fig. 3.   Example comparison result showing the utility ratio of per node transmission and reception in case of node to node communication and node to access point communication.

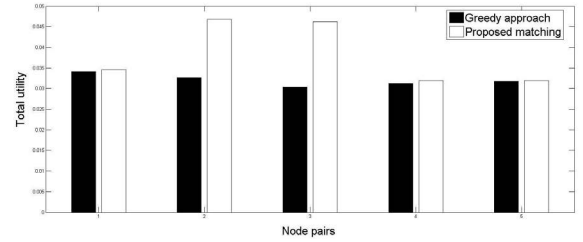lower than paired node-to-node communication over a much shorter distance.

Fig. 4.   Example comparison result showing how proposed matching algorithm can improve total utility of node pairs

Fig. 4 reflects the performance of the proposed algorithm in the node pairing or matching algorithm. In this case, the comparison result shows the efficiency of using the proposed refined Irving's matching algorithm for 5 pairs of nodes with quota. The proposed algorithm outperforms the greedy algorithm where the nodes are paired by considering the neighboring nodes for pairing. The reason behind the efficiency of the proposed algorithm is the combination of quota based approach and best utility based selection of nodes for pairing. In the figure, the total utility of node pair 2 and 3 justify the effectiveness of the refinement in Irving's matching algorithm. It also indicates that the cooperation between IoT nodes tremendously increase the total utility of such kind of one-to-many node pairing. This phenomena also indicates that with a large number of node set and quota based pairing of nodes will increase the overall utility of the entire set of node domain.

VI. CONCLUSION

The proposed system model in Fog computing paradigm endorses an efficient way for short range device to device communication in order to utilize the full potential of the resourceful IoT nodes at the edge of the network hierarchy. The proposed refinement in the classical stable matching or pairing algorithm ignites edge computing with better utility factor in terms of enabling a proficient way of device to device communication. In future, we will expand our proposed system

model and algorithm by integrating more dynamic context of optimal resource allocation.

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