Interest, Energy and Physical-Aware Coalition Formation and Resource Allocation in Smart IoT Applications

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***Abstract*—In this paper, the problem of coalition formation among Machine-to-Machine (M2M) communication type devices and the resource management problem is addressed. Each M2M device is characterized by its energy availability, as well as by differentiated interests to communicate with other devices based on the Internet of Things (IoT) application that they jointly serve. Physical ties among devices also exist based on their physical distance proximity and communication channel quality. Those three factors: energy availability, interest and physical ties, are considered into the coalition formation process and the coalition-head selection. Each M2M device is associated with a holistic utility function, which appropriately represents its degree of satisfaction with respect to Quality of Service (QoS) prerequisites fulfillment. Given the created coalitions among the M2M devices, a distributed power control framework is proposed towards determining each M2M device's optimal transmission power in order to fulfill its QoS prerequisites. The performance of the proposed approach is evaluated via modeling and simulation and its superiority compared to other state of the art approaches is illustrated.**

Keywords—Machine-to-Machine (M2M) communication; Internet of Things (IoT); coalition formation; interest ties; resource management.

I. INTRODUCTION

As wireless communication systems and networks evolve, the Internet of Things (IoT) is an emerging topic of great technical, social, and economic significance. Projections for the impact of IoT on the Internet and economy are impressive, with some anticipating as many as 100 billion connected IoT devices and a global economic impact of more than $11 trillion by 2025 [1]. At the same time, however, the IoT raises several significant technological challenges that could stand in the way of realizing its potential benefits. Among those significant challenges, the connectivity of the devices in a wide range of IoT applications, e.g., smart grid/metering, smart farming, health monitoring, smart homes, etc., arises as one of the most interesting research and innovation areas. The Machine-to-Machine (M2M) communication provides the IoT with the connectivity, relying on point-to-point communication using embedded hardware modules on the M2M connected devices and wireless networks. More specifically, M2M communication seeks spectrally- and energy-efficient ways to provide ubiquitous connectivity among a massive number of low-cost devices without, or with, minimal human interaction.

A. *Related Work*

In the vast majority of IoT applications, energy-efficiency has become an important objective in resource allocation due to the growing proliferation of M2M devices, which are often battery operated and deployed in areas where frequent human access or battery replacement is not always feasible [2]. Therefore, towards overcoming the wireless access congestion problem and, in parallel, to improve the energy efficiency of M2M devices, the joint clustering of devices and resource management arises as a promising solution. Various M2M devices clustering methods have been proposed in the recent literature based on different criteria, e.g., M2M devices' achievable signal to interference plus noise ratio [3], transmission delay [4], etc. An immediate and intuitive benefit of such clustering results from the induced hierarchy for management and control.

The notion of "data priority" has been also proposed in the literature, which means that the data flows from specific M2M devices have higher priority to be transmitted and collected compared to others. The criterion of data priority has been also considered towards proposing energy-efficient and congestion-mitigated clustering algorithms and resource management approaches. In [5], the authors study a healthcare IoT application, where the devices' clustering is based on the health-based priority of their transmitted data. In [6], the authors propose a data-centric clustering in a resource-constrained M2M network by prioritizing the quality of overall data over the performance of individual devices. Moreover, in [7] the problem of energy-efficient clustering is studied by jointly considering cluster formation, transmission scheduling and power control, while the transmission powers of the scheduled devices are considered towards ensuring concurrent reliable transmissions in the cluster structure. Furthermore, in [8] the authors assume an existing clustering and they enforce the cluster-head to coordinate the congestion within the cluster via assigning weights to the devices based on criteria like priority of data, energy availability, and mobility of the devices.

B. *Paper Contributions*

In this paper, it is the first time in the literature to the best of our knowledge that a joint interest, energy and physical-aware framework for coalitions formation among wireless IoT devices and an energy-efficient resource allocation in M2M

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communication is proposed. In our proposed framework, the notion of coalitions is adopted instead of clusters, due to the fact that the M2M devices choose to create a collaborative union / partnership based also on their mutual interest to communicate with each other. Moreover, M2M devices' energy availability and physical awareness, referring to topological characteristics and communication channel quality, are considered in order to create more efficient and accurate coalitions. The proposed framework consists of two fundamental stages. At the first stage, the interplay of interests' interactions among wireless IoT devices and their energy levels are exploited towards establishing coalitions among devices by also considering the physical proximity constraint and the communication channel quality. A coalition-head will be periodically determined for each coalition in a reasonable window of timeslots. The coalition-head is in charge of more functionalities and responsibilities, i.e., data aggregation, processing, data compression before relay, transmission to the central data aggregator / evolved NB (eNB), etc., compared to the rest of the M2M devices.

At the second stage, the Quality of Service (QoS) prerequisites of M2M devices are formulated via a holistic utility function, which can easily adapt to different IoT applications due to its generic form, thus providing us the benefit of a universal proposed approach. Each M2M device aims at the maximization of its utility in a selfish and distributed manner towards fulfilling its QoS prerequisites. An energy-efficient resource allocation framework is proposed as a distributed optimization problem of each M2M device's utility function towards determining the optimal transmission power of each wireless IoT device. Simulation results show that the proposed framework can form wireless IoT devices' coalitions rationally among a group of M2M devices, allocate the resources in an energy-efficient manner and therefore jointly guarantee the coordination of the devices, increase the energy-efficiency of the overall system and prolong the battery-life of the M2M devices.

C. *Paper Outline*

The remaining part of the paper is organized as follows. Section II elaborates the details of the adopted system model. In Section III, the interest, energy and physical ties among the M2M devices are presented, towards explaining the criteria of coalition formation among the M2M devices. In Section IV, the methodology towards selecting the coalition-head is presented, as well as the actual proposed framework for the coalition formation. In Section V, the energy-efficient resource allocation problem is formulated and solved in a distributed manner. The performance of the proposed approach is evaluated in detail through modeling, simulation and comparisons with other methods in Section VI. Finally, Section VII concludes the paper.

II. SYSTEM MODEL

We consider the uplink of a Long Term Evolution (LTE) / LTE-Advanced Machine-to-Machine (M2M) communication type network consisting of an evolved NB (eNB) and multiple LTE based M2M devices, e.g., sensors, actuators, etc. The eNB serves a region $\Re$ and covers an area of radius R_0, supporting multiple types of requested services by the M2M devices. Furthermore, within the region $\Re$ there are deployed $|M|$ M2M devices, where their corresponding set is denoted by $M = \{1,...,m,...,|M|\}$. These devices can be placed at any possible locations, e.g., in offices to homes/apartments, in farms, factories, etc., supporting various IoT applications, e.g., smart homes: smart thermostats, smart lighting systems, smart factories: logistics, etc. The sensors can collect data as per their functionality and send the same to the central application controller. Considering sensors' data collection, two types of communication are possible: (a) eNB-M2M communication, i.e., each device communicates through the eNB and (b) direct M2M communication, i.e., direct communication among M2M devices. In this paper, we consider direct M2M communication.

Towards improving the energy-efficiency and mitigating the congestion of the overall system, as well as prolonging the life-time of the M2M devices, the concept of coalition formation among the M2M devices is proposed. The M2M devices create $|C|$ coalitions among each other and the coalitions' set is denoted as $C = \{1,...,c,...,|C|\}$. Each coalition c has a coalition-head ch_c, $ch_c \in M$, who is in charge of collecting the data from the $|M_c|$ M2M devices belonging to the coalition $c, c \in C$, and forwarding the information to the eNB for further processing and dissemination. Moreover, the radio resources can be divided into timeslots (TDMA) or resource blocks (OFDMA) to be allocated to the individual M2M devices. Thus, the only existing interference to the devices' transmissions stems from the thermal noise components and the M2M devices' control signals, which can be regarded together as an Additive White Gaussian Noise (AWGN) process, with constant power density I_0. In the rest of this paper, the terms wireless IoT devices and M2M devices will be interchangeably used.

III. INTEREST, ENERGY AND PHYSICAL TIES IN M2M COMMUNICATION

The interest, energy and physical behaviors of M2M devices have a strong impact on the efficacy and efficiency of M2M communication. Within an IoT application, the M2M devices have different interests to interact with each other in order to achieve a common goal, thus they are willing to form coalitions. For example, in a smart home application there are included many M2M devices, e.g., smart thermostats, connected lights, smart fridge sensors, smart door lock sensors, etc. The smart thermostats and the sensors measuring the temperature have greater interest to communicate with each other, form a coalition and transmit their data to the coalition-head, which further transmits all the collected data to the eNB for further exploitation and decision making from the end-user's side, e.g., increase the average temperature via remotely accessing the smart thermostat. The same holds true for the set of sensors participating in the smart lighting system or smart fridge application and so on and so forth.

Except for the interest of interaction among IoT devices, their energy availability, their physical proximity and channel quality should be considered in order to form the coalitions and select the coalition-head. The concept of considering the communication interest among the M2M devices in order to form the coalitions among them is one of the fundamental novelties of this paper. As explained in Section I.A, the majority of the literature considers only physical related parameters, e.g., distance among the devices, energy-efficiency, etc., or network related parameters, e.g., transmission delay, signal-to-interference-plus-noise ratio, etc., in order to organize the M2M devices into clusters, without considering their real need to exchange information among each other in order to efficiently operate within a smart IoT application.

A. Communication Interest among Wireless IoT Devices

In the proposed framework, interest ties measure the strength of the relation between M2M devices that are related to each other. This relation among devices is established, while considering the operation of each M2M device and its involvement to a specific IoT application. In the proposed framework, the notion of interest ties is used towards reflecting the weak or strong interest connections and interactions between M2M devices. Therefore, reliable M2M communication links are established within a group of M2M devices for energy-efficient data transmission.

Based on the devices' interest to communicate with each other, we present the interest ties among the $|M|$ wireless IoT devices by a symmetric matrix $\mathrm{I}=\{i_{\mathrm{m,m'}}\}_{|\mathrm{M}|\times|\mathrm{M}|}$, where each element $i_{\mathrm{m,m'}}$ (or equivalently $i_{\mathrm{m',m}}$) expresses the interest of the m^{th} device to communicate and exchange information with the $m'^{\text{ th}}$ device. We assume that the devices m and m' have the same interest to communicate with each other, thus the interest matrix I is symmetric. The interest degree $i_{\mathrm{m,m'}}$ ranges from zero to one, i.e., $i_{\mathrm{m,m'}}\in[0,1]$, where the values close to zero reflect less interest of communication among the two devices, while the values close to one show willingness of close collaboration among the devices. We propose a threshold based M2M link establishment, i.e., an M2M link among two wireless IoT devices is established if their interest tie is above a threshold i_{thr}, $i_{\mathrm{thr}}\in[0,1]$. It is noted that different interest thresholds can be assumed for different IoT applications, thus the proposed communication interest metric can be applied in various IoT applications.

B. Availability of Energy

The majority of wireless IoT devices are battery-enabled with limited energy and constrained battery life, thus considering their energy-availability in the coalition formation process, as well as for selecting the coalition-head is critical. Acting as a coalition-head results to increased battery consumption for the wireless IoT device, due to the collection, processing and transmission of a large amount of data to the eNB. Thus, the coalition-head should periodically change in order to guarantee fairness among the wireless IoT devices. Let us denote the available energy of each wireless IoT device as E_m, $m\in M$. Each wireless IoT device is characterized by an energy availability (EA) indicator, i.e., $EA_m=\dfrac{E_m}{\underset{\forall m'\in M}{max}\{E_{m'}\}}$, where $EA_m\in[0,1]$. The energy-availability factor expresses the relative energy-availability of each M2M device and will be considered in the coalition-head selection process (Section IV.A).

C. Physical Ties

Towards establishing an energy-efficient M2M link among the wireless IoT devices, the physical proximity of the devices, as well as the quality of their communication channel should be considered. We adopt a symmetric matrix $\mathrm{Q}=\{q_{\mathrm{m,m'}}\}_{|\mathrm{M}|\times|\mathrm{M}|}$ towards indicating the physical proximity and channel quality between the m^{th} wireless IoT device and the $m'^{\text{ th}}$ device. For simplicity purposes, and without loss of generality, we assume the same communication channel gain among the devices m and m' and vice versa. We set the range of $q_{\mathrm{m,m'}}$, as $q_{\mathrm{m,m'}}\in[0,1]$ and we assume that the physical proximity and channel quality degree between two wireless IoT devices is directly proportional to the value of $q_{\mathrm{m,m'}}$. A threshold value q_{thr} is considered in our proposed framework, where if $q_{\mathrm{m,m'}}>q_{\mathrm{thr}}$ an M2M communication link among m,m' devices can be potentially established.

IV. COALITION FORMATION

A. Coalition-Head Selection

Let us consider a subset $M'\subseteq M$ of wireless IoT devices, which will be a candidate coalition over the set of all wireless IoT devices M. A coalition-head should be selected among the IoT devices that have already established the coalition, towards collecting their data and reporting them to the IoT data aggregator/eNB and vice versa send requests and/or commands to the wireless IoT devices. A representative Importance Factor (IF_m) is defined for each M2M device $m,m\in M',M'\subseteq M$ showing its importance to be selected as a coalition-head, while considering the overall interest, energy and physical ties, related to this device m.

Let us define the IF_m for each wireless IoT device $m,m\in M',M'\subseteq M$ as follows:

$$IF_m=EA_m\sum_{m\in M'} i_{m,m'}q_{m,m'},\quad \forall m,m'\in M',m\neq m' \tag{1}$$

where EA_m considers the energy availability of the m^{th} M2M device and $\sum_{\mathrm{m}\in\mathrm{M'}} i_{\mathrm{m,m'}}q_{\mathrm{m,m'}}$ synthetically represents the interest of the rest of the devices within the coalition to communicate with the m^{th} device, while considering their physical proximity, as well as their communication channel quality. Then, the coalition-head ch_c of the coalition $M'\subseteq M$ is the m^{th} wireless IoT device that has the maximum importance factor IF_m, i.e., $ch_c=\underset{m\in M'}{arg\,max}\{IF_m\}$.

B. Coalition Formation

A multi-factor coalition formation process is proposed considering the interest ties and the physical proximity and the transmission channel quality ties among the M2M devices, as well as their energy availability in order to select the coalition-head. An iterative methodology is proposed towards determining the coalitions among the wireless IoT devices within a group of devices. The main steps of the proposed coalition formation methodology are as follows:

1. Initially, we consider the whole set of wireless IoT devices, i.e., M , as an initial coalition, thus $M' = M$.

2. For the considered coalition M', the coalition-head can be determined via utilizing equation (1) and we have $ch_c = \underset{m \in M'}{arg\,max}\{IF_m\}$.

3. Considering the rest of wireless IoT devices in the coalition M', if the following conditions hold true

$$i_{\mathrm{m,ch_c}} \geq i_{\mathrm{thr}}$$
$$q_{\mathrm{m,ch_c}} \geq q_{\mathrm{thr}},\ \forall \mathrm{m} \in \mathrm{M'} - \{\mathrm{ch_c}\}$$

then the m^{th} wireless IoT device belongs to the same coalition as ch_c. The devices that do not satisfy the above conditions formulate another coalition $M'' \subseteq M'$.

4. Set $M' = M' - M''$ and if $|M'| > 1$ go to step 2, otherwise stop.

Based on the above coalition formation methodology, we are able to dynamically determine (a) the number of coalitions, (b) the specific ID of the M2M devices that belong to each coalition, and (c) the coalition-head of each coalition. The coalition formation algorithm can be executed per timeslot or for more practical and realistic scenarios per a reasonable window of timeslots, where the interest, energy and physical ties will have a substantial difference.

V. ENERGY-EFFICIENT RESOURCE ALLOCATION

Towards treating M2M devices' diverse and multiple QoS prerequisites under a common optimization framework, the concept of utility function is adopted. Each M2M device $m, m \in M$ adopts a utility function towards expressing its Quality of Service (QoS) prerequisites, which are differentiated per type of IoT application that the M2M device participates. The adopted utility function is a continuous, differentiable function with respect to M2M device's transmission power P_m and is given as follows:

$$U_m(P_m) = \frac{W \cdot f_m(\gamma_m)}{P_m} \tag{2}$$

where W is the system's bandwidth and $f_m(\gamma_m)$ is M2M device's efficiency function representing the successful transmission probability of M2M device m belonging in cluster c to its cluster-head ch_c . The efficiency function $f_m(\gamma_m)$ is a continuous, differentiable and increasing function of γ_m and has a sigmoidal shape such that there exists γ_m^{target} below which $f_m(\gamma_m)$ is convex and above which $f_m(\gamma_m)$ is concave. For presentation purposes, we adopt $f_m(\gamma_m) = \left(1 - e^{-A\gamma_m}\right)^M$, where *A, M* are real valued parameters controlling the slope of the sigmoidal-like function [9]. It is noted that for different IoT applications differentiated γ_m^{target} are requested by the M2M devices. These differentiated M2M devices' QoS prerequisites can be captured by the adopted efficiency function via the control parameters *A* and *M*.

The goal of each wireless IoT device is to maximize its perceived satisfaction from the resource allocation towards extending its battery-life. Towards achieving this goal, the maximization of each M2M device's utility is performed via determining the optimal transmission power in a distributed manner. Therefore, the maximization problem of each M2M device's utility function is formulated as follows.

$$\max_{P_m \in \left[0, P_m^{Max}\right]} U_m(P_m) \tag{3}$$

where P_m^{Max} is the maximum available power of the m^{th} M2M device. The above optimization problem has a unique optimal transmission power, due to the form of the utility function which can be easily proven that it is quasi-concave with respect to the M2M device's transmission power P_m . Therefore, the optimal transmission power P_m^* of each M2M device is given as follows:

$$P_m^* = min\left\{\frac{\gamma_m^* I_0}{G_m}, P_m^{Max}\right\} \tag{4}$$

where γ_{m}^* is the unique positive solution of the equation $\frac{\partial U_m(P_m)}{\partial P_m} = 0$. Based on the above presented analysis, it is concluded that each M2M device can determine in a distributed manner its optimal transmission power, while considering its communication channel conditions, as well as its QoS prerequisites fulfillment.

VI. NUMERICAL RESULTS

In this section, we provide some numerical results evaluating the operational features and performance of the proposed framework. Initially, in Section VI.A we focus on the operation performance achieved by our proposed framework, in terms of scalability, energy saving and prolongation of M2M devices' battery life. Then, in Section VI.B, we provide a comparative evaluation of our proposed approach against other existing approaches in the literature with respect to several metrics, e.g., energy consumption and system's scalability.

A. Proposed Approach: Properties and Operation

In the following, we consider a wireless IoT environment consisting of a number of wireless IoT devices $|M|=50$ randomly distributed in a square coverage area *200m x 200m* and the eNB resides at the center of the square. The duration of each timeslot is *0.5msec*. Three different simulation scenarios are considered as follows: (a) random interests among M2M devices, (b) best-case scenario, i.e., the M2M devices that are close to each other have high interest to communicate and the M2M devices that are far from each other have small communication interest, and (c) worst-case scenario, i.e., the exact opposite conditions compared to the best-case scenario hold true.

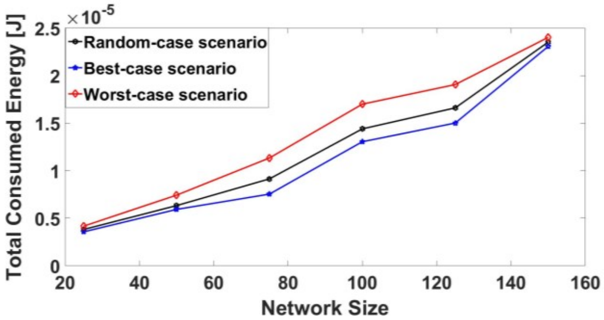

Fig. 1. Total consumed energy as a function of the network size.

Fig. 1 represents the total consumed energy in the network as its size increases for a specific timeslot considering the formulated coalitions among the M2M devices. The results reveal that in the case of high interests among neighbor M2M devices (i.e., best-case scenario), the corresponding created coalitions among them contribute to energy saving. The above outcome is observed due to the fact that M2M devices with high communication interest reside close to each other, thus their communication channel conditions are good and their corresponding power consumption is low. The exact opposite holds true in the case that the M2M devices with high communication interest reside far from each other (i.e., worst-case scenario). In the latter case, the M2M devices spend a lot of energy to communicate due to their deteriorated channel conditions. The third scenario with random communication interests among the M2M devices represents an average state of a wireless IoT environment where M2M devices with high communication interest reside in an average distance among each other, thus the corresponding total power consumption of the devices lies in the middle of the best and worst-case scenario. Moreover, the results of our proposed approach, as presented in Fig. 1, show the scalability of our algorithm supporting a large number of M2M devices.

Fig. 2 illustrates the energy consumption of the three scenarios discussed above, as time evolves, i.e, for *500* timeslots, considering $|M|=50$ M2M devices. The results reveal that the proposed framework achieves the stability of the overall system with respect to the total power consumption. More specifically, the coalitions, as well as the corresponding coalition-heads may vary as the time evolves, however the formulated coalitions achieve stability with respect to the overall transmission power of the M2M devices. Moreover, the total consumed power follows the same trend as presented above considering the three scenarios, i.e., the best and worse-case scenario have the least and maximum power consumption, respectively, while the scenario with random communication interests among the M2M devices is characterized by an average power consumption.

Fig. 3 presents the percentage of M2M devices that run out of battery (i.e., "dead" devices) as the time evolves. For demonstration purposes only and without loss of generality, we assume that the initial available energy of each M2M device is $E_m=0.01mJ$. The results reveal that the M2M devices in the worst-case scenario run sooner out of battery, while the opposite holds true for the best-case scenario, due to the fact that the M2M devices consume less power per time slot (Fig. 1), as well as the time evolves (Fig. 2).

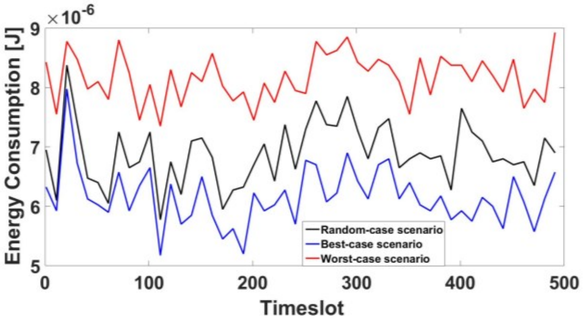

Fig. 2. Energy consumption as a function of the time.

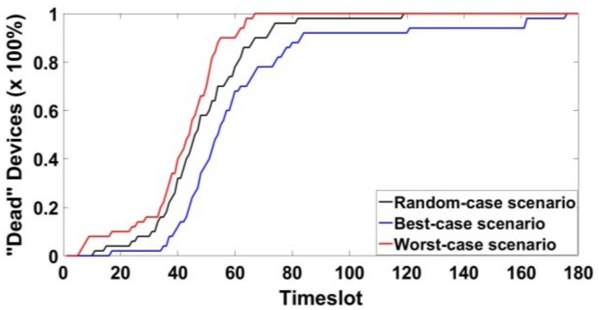

Fig. 3. Percentage of devices that run out of battery as a function of time.

B. Comparative Evaluation

In this subsection, we provide a comparative study illustrating the benefits of jointly considering interest and physical ties among the M2M devices in order to create the corresponding coalitions. Specifically, we compare three different approaches considering the coalition formation process, as follows:

a. The proposed coalition formation approach as it has been proposed in this paper, which considers jointly the interest and physical ties among the M2M devices, as presented in Step 3 of the Coalition Formation algorithm in Section IV.B. This coalition formation scenario is called *i-q-approach*.
b. Considering only the physical ties among the M2M devices in order to create the coalitions, i.e., *q-approach*, and
c. Considering only the interest ties, i.e., *i-approach*.

It is noted that especially in the q-approach the M2M devices will create coalitions based on their physical proximity and their good communication channel conditions without however having high interest to communicate with each other. Therefore, the corresponding coalition-head per each coalition will mainly act as a relay reporting to the eNB the collected information from the M2M devices in the same coalition for further exploitation. For example, assume a room where sensors of temperature and light coexist and belong to the same coalition due to physical proximity and the coalition-head is a smart M2M thermostat. The smart thermostat will collect the data from the sensors of temperature, aggregate, process them and perform one transmission of the processed information to the eNB. On the other hand, considering the information collected from the light sensors, the smart thermostat coalition-head will act as a relay to transmit their information to the eNB for further processing and exploitation.

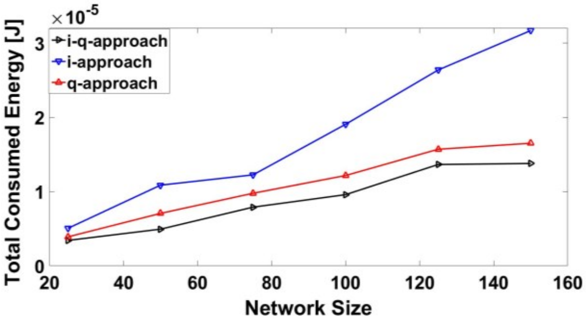

Fig. 4. Total consumed energy as a function of the network size considering three comparative scenarios: (a) i-q-approach, (b) q-approach and (c) i-approach.

On the other hand, considering the i-approach, where the coalitions are formed based only on M2M devices communication interests, the above presented multi-transmission problem from the coalition-head's side is solved, due to the fact that the coalitions will be formed with M2M devices which have high interest to communicate with each other. Thus, the coalition-head will first collect the information from all the M2M devices in the same coalition, process it and then transmit it to the eNB.

Towards comparing the above presented scenarios in a fair manner, we propose the Interest-based Aggregation Efficiency (IAE) factor, as follows:

$$IAE = |M_c| - \sum_{m \in M_c} i_{m,ch_c} \tag{5}$$

Considering the smallest following integer of IAE, i.e., $\lceil IAE \rceil$, we determine the number of transmissions that each coalition-head should perform in order to report the collected data from its M2M devices residing in the same coalition to the eNB, either acting as relay or transmitting a processed group of collected data. In Fig. 4, we compare the total consumed energy under the three different comparative approaches (i.e., i-q, i and q-approach) as a function of the network size. The comparison of the three different coalition formation approaches reveals the pure benefits in energy saving, while considering jointly the interest and physical ties among the M2M devices in order to form the coalitions. The main drawback of the q-approach is that the coalition-heads have to perform multiple transmissions (i.e., large values of $\lceil IAE \rceil$) in order to report the collected data to the eNB. On the other hand, the main drawback of the i-approach is that the M2M devices in the coalition may reside in large distances among them, thus they consume increased transmission power to send their data to the coalition-head, which needs few or even one transmission to send the processed data to the eNB (i.e., small value of $\lceil IAE \rceil$). The combined benefits of physical proximity and increased communication interest among devices is achieved by the i-q approach, which results to decreased energy consumption.

VII. CONCLUSIONS

In this paper, the problem of interest, energy and physical-aware coalition formation and resource management in smart IoT applications is studied. The concept of interest ties among M2M devices is introduced, towards expressing their communication interest depending on the involved IoT application. The interest ties along with the physical ties and M2M devices' energy availability are considered in order to form coalitions among them and select the corresponding coalition-head. A distributed resource management mechanism is proposed towards determining the optimal transmission power of each M2M device in order to fulfill its QoS prerequisites. In the future, the authors would like to broaden the area by implementing and testing the proposed framework in a realistic testbed environment, where multiple M2M devices participating in different IoT applications with different corresponding interest ties will be included. Towards this direction, an IoT Lab is being developed within the Institute for Systems Research at the University of Maryland, College Park.

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