Exploiting Object Group Localization in the Internet of Things: Performance Analysis

Salvatore D'Oro, *Student Member, IEEE,* Laura Galluccio, *Member, IEEE,* Giacomo Morabito, and Sergio Palazzo, *Senior Member, IEEE,*

***Abstract*—In the *Internet of Things* (IoT) localization of objects is crucial for both information delivery and support of context-aware services. Unfortunately, the huge number of mobile objects which will be included in the IoT can result in a significant amount of signaling traffic for the purpose of location discovery and update. The major contributions of this paper are based on a simple evidence: in most IoT scenarios several objects move together as they are carried by a human or a vehicle, i.e., a phenomenon that we refer to as *object group mobility* (OGM) naturally emerges. OGM can be exploited to reduce signaling traffic and to improve the accuracy of object localization. More specifically, in this paper: i) we introduce the OGM concept and explain how, by means of a collective agent representing a group of objects as whole, it is possible to reduce signaling traffic and improve accuracy in object localization; ii) we derive an analytical framework to assess the advantages of the proposed approach; iii) we validate the analytical framework through extensive simulations.**

***Index Terms*—Internet of Things (IoT), Object Localization, Group mobility, Mobility management.**

I. Introduction

An explosive growth in the number of objects connected to the Internet is expected in the next few years with a forecast of up to 50 billions by 2020 [1]. A sudden consequence of the high expectations in terms of market opportunities is the continuously and rapidly increasing attention on the *Internet of Things* (IoT) which has characterized the last few years.

One of the major problems that IoT solutions will have to face is related to the object mobility management which is needed for both information delivery and object localization. More specifically, since most of such objects will be mobile, a large amount of signaling traffic is expected to be generated to keep updated information about their current positions. Note, in fact, that IoT will likely run IPv6 at the networking layer and, thus, mobility management solutions will be based on Mobile IPv6 (MIPv6)[2]. This requires the establishment of an IPSec channel for each *binding update* message[1] sent by a mobile node to its home agent. Clearly this raises serious scalability concerns when the number of mobile nodes is expected to hugely increase.

The final published paper is available at DOI: 10.1109/TVT.2014.2356231.

Authors are with Dipartimento di Ingegneria Elettrica, Elettronica ed Informatica, University of Catania, Italy, V.le A. Doria 6, 95125 Catania e-mail: {name.surname}@dieei.unict.it

[1]Binding messages are sent every time a node changes its point of attachment to the Internet

In this paper we introduce and discuss a solution that faces the above issues by exploiting the so called *object group mobility* (OGM), a phenomenon that naturally emerges as usually IoT objects are carried by a human or a vehicle together with several other objects. For example, goods produced by a supply chain are carried on trucks until they are delivered to a retail store or things in a bag are carried around as one single object until they are not put at their right place.

Actually, the challenges and opportunities related to OGM have been deeply investigated by IETF in the context of *Network Mobility* (NEMO) [3] and a specific IETF RFC has been created. More specifically, in the NEMO proposal, a Mobile IP compliant methodology has been introduced to support the mobility of an entire network of IP devices. Indeed, the traditional Mobile IP supports the ability for a single mobile device to change its point of attachment to the Internet without disrupting the transport and higher layers; differently, the objective of the Network Mobility (NEMO) is to enable a router to act as a mobility agent on behalf of an entire network of IP devices.

NEMO relies on the use of a Home Agent (HA) and a Mobile Router (MR) which binds to the HA when away from its home network. HAs then forward all packets destined to a mobile network to the MR through a tunnel. Reverse traffic is tunneled back to the HA for delivery. Partial implementations of the NEMO proposal are available in the projects *Nautilus 6* [4] and *Cisco Mobile network* [5], as well as in [6] where the design and implementation of a NEMO testbed is presented. In [7], taking inspiration from [8] and [9], a NEMO-like approach is applied to a vehicular scenario. More specifically, in [7] a vehicle realizing that it is leaving the coverage area of a base station and entering another one, exploits multihop relaying through other vehicular nodes to acquire a new IP address. The relaying vehicles are those moving either in opposite lanes or in the same lane. So a vehicle performs a seamless pre-handover to improve the handover efficiency and keep the connection on. Also in [10] the integration of the NEMO proposal in vehicular scenarios is addressed. Similarly, in [11] the issue of supporting seamless handover between earth stations in satellite scenarios using a NEMO-like approach is discussed.

Object group mobility in IoT scenarios has also been exploited to reduce signaling in the context of M2M communications within 3GPP as well [12], [13]. In [12] and [13] for example, dynamic groups are considered, i.e., objects can join and leave the group. However, the proposed solutions are specifically tailored for M2M systems. Therefore, the (very usual) cases in which distinct objects belonging to the same group use different wireless access technologies are not addressed.

Our paper goes beyond the previous literature in several ways. First in our work we consider the case in which nodes of the same group are equipped with different network interfaces, that is, the group is heterogeneous. In this way, we will show that using our approach it is possible to increase location accuracy. Furthermore, we discuss how dynamic membership of objects within a heterogeneous group can be effectively managed (dynamically vary, increase in size, reduce, split, join, etc.) while this was not addressed in the previous literature. Finally, we introduce the use of a *collective agent*, which allows to further reduce the signaling overhead while keeping updated the information relevant to the group members.

Accordingly, the most significant contributions of this paper can be summarized as follows: i) we consider *object group mobility* (OGM) and we show how OGM can be exploited to reduce signaling traffic and to improve the accuracy of object localization; ii) we illustrate how, by means of a *collective agent* representing a group of objects as a whole, it is possible to reduce signaling traffic and improve accuracy in object localization; ii) we derive an analytical framework to assess the advantages of the proposed approach; iii) we run a simulation experiment to validate the analytical framework and assess the proposed solution.

The rest of this paper is organized as follows. The notation and system architecture are introduced in Section II. Section III introduces the OGM concept and illustrates how it can be used to achieve more accurate object localization and reduced signaling for mobility management purposes. An overview of mobility management procedures in IoT scenarios is given in Section IV by illustrating basic operations and their functioning. In order to evaluate the advantages offered by exploiting the OGM concept in the IoT, an analytical framework is derived in Section V that shows how the OGM concept gives benefits when the network is dense. Accuracy of the analytical framework is assessed in Section VI through a set of simulations, which are used to evaluate the performance improvements achieved by exploiting the OGM concept. Finally, in Section VII conclusions are drawn.

II. System model and notation

To date there is no universal agreement on a specific and detailed architecture for the IoT[2]. Nevertheless, in order to introduce the notation which will be used in the rest of the paper, we provide a general reference architecture. This only takes the basic functional elements into account that, even if named in different ways, can be found in all existing proposals.

We consider a network providing access in a given geographical area denoted as *interest area*, to several heterogeneous objects equipped with some wireless interface: for example, some devices could be wireless sensors or actuators equipped with IEEE 802.15.4; others can be smartphones or tablets equipped with 3G/UMTS or IEEE 802.11; others can be items identified through RFID tags. We assume that all devices have an IPv6 address. This assumption is motivated by the large literature and activities of the standardization bodies [16], [17] which anticipate that, in the Internet of Things, all network nodes will have IPv6 addresses. Consequently, several activities are ongoing aimed at mapping any identification scheme into IPv6 addressing [18], [19].

The problem we address is related to the management of the mobility for this multitude of devices which coexist in the same area without knowing about each others because of the different wireless interfaces used.

The interest area is assumed to be organized into *ambiences*, as shown in Figure 1. An *ambience* is a limited space with homogeneous physical characteristics (temperature, humidity, luminosity, etc.) where objects (even partially) sharing the same intents are located and can interact with each others to support added value services. In the recent literature on smart computing, ambiences can often be identified with the so called *contexts* or *rooms*, e.g. [20], [21]. Let us label the different set of ambiences in the area of interest as $A = \{a_1, a_2, ..., a_M\}$, where a_i identifies the i-th ambience.

As usually assumed in the IoT paradigm, the presence of many objects into the same ambience leads to multiple mutual interactions between them and the ambience itself. Consequently, a modification of objects' features as a consequence of these interactions is likely to occur.

However, due to the limited computing capabilities of the communication/processing devices embedded into objects, a high degree of "ambience awareness" calls for availability of dedicated servers embedded into the ambience. This has indeed been proposed by relevant architectural solutions for smart environments (e.g., [20], [21], [22], [23]) and IoT [14], [24].

In the following it will be also assumed that the area of interest is served by an access network, denoted as *interest area network*[3], connected to the rest of the Internet. Moreover, as sketched in Figure 1, we assume that multiple heterogeneous access points (APs) provide communication support to objects by using multiple access technologies. Accordingly, for example, WiFi or Bluetooth APs could be available, as well as IEEE 802.15.4 gateways, RFID readers, etc. To this purpose, let us denote $\psi(AP)$ the access technology used by a generic AP, where each access point can cover multiple ambiences. The set of ambiences covered by an AP is denoted as $C(AP)$.

Let n be a node located in ambience a_n and equipped with a wireless interface of technology $\psi(n)$. Then, n will be able to connect only to access points which support identical technology.

According to MIPv6 [2], each node n has a *home network* $HN(n)$ where a home agent $HA(n)$ keeps information about the position of node n updated. The home network may be not the same network where the mobile node is currently attached; the latter is typically referred to as the *foreign network* $FN(n)$ [2].

To better understand the roles of the different elements

[2]A comprehensive overview of proposed approaches has been carried out within the IoT-A project [14], [15]

[3]In Figure 1 the context server is placed in the interest area network although in principle, it could be not.

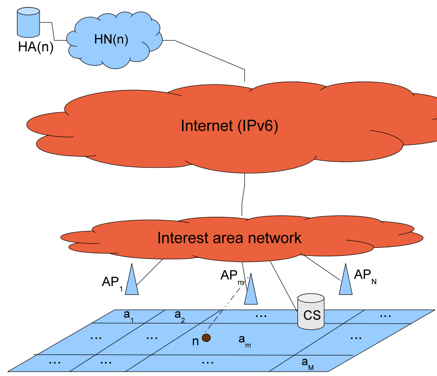


Fig. 1. System architecture.

envisioned in our system, let us consider a typical IoT application scenario: smart building. In this case ambiences are the rooms of the building and typical objects to be considered are personal items (smartphones, laptops, tablets, health sensors, etc.) as well as environmental sensors and actuators. These objects will access the network through IEEE 802.11 and/or IEEE 802.15.4 interfaces and therefore, it is expected that there will be several IEEE 802.11 and IEEE 802.15.4 access points in the building. Furthermore, a server will be deployed which collects information about the position of the nodes located in the building as well as the services they offer. Such information will be exploited to create context-aware applications: in other words the above server is the CS in the smart building scenario.

III. Exploiting Group Mobility in IoT scenarios

Mobility of nodes is a relevant feature to be considered in the design of location update protocols. In the literature there has been a relevant effort to characterize human mobility [25], [26], [27], [28].

However, modeling *things*' movements is still an open issue which requires the definition of completely new experimental data and models. Nevertheless, an obvious observation can be drawn: objects, i.e., nodes, usually move in groups. That is, objects typically aggregate around a carrier (a person, a truck, a car, a bag, a box, etc.). This occurrence can be modeled through the concept of *object group mobility* (OGM) and the carrier around which objects aggregate is denoted as *group master* (GM). Both the master and the moving nodes denoted as *slaves*, are IoT items. The group master, in particular, is assumed to be equipped with multiple wireless interfaces.

Emergence of group mobility has been observed in several wireless scenarios and exploited to reduce energy consumption and to preserve privacy in mobility management schemes [29], [30], [3]. In a IoT scenario, group mobility can be exploited for reducing mobility management overhead as well.

To this purpose, the GM assigns addresses available in its "home network" to the slaves, so registering them as nodes of its network. Accordingly, slaves set the address of the GM home network as their care-of-address at their home agents.

As a consequence, when slaves in a group move and thus the foreign address changes, no binding messages will be exchanged among slaves and their home agents: only the GM will inform its home agent about the care-of-addresses of the slaves in the group.

It follows that the use of group mobility allows to drastically reduce the amount of signaling needed for mobility management purposes as illustrated in Section VI.

In a IoT scenario, nodes belonging to a group and moving together are intrinsically heterogeneous and thus equipped with different access technologies. This heterogeneity allows to guarantee higher accuracy in location estimation as compared to NEMO or Mobile IP solutions. Also, in this way, added value services, which take location information into account, can be supported more efficiently.

A simple example can be used to support the above claim. Let n_0 and n_1 be two nodes[4] belonging to the same group, equipped with 2 different access technologies ψ_0 and ψ_1, respectively.

Suppose that nodes n_0 and n_1 access the network by means of two access points, AP_0 and AP_1, covering two different sets of ambiences, Φ_0 and Φ_1.

By considering n_0 and n_1 individually, we expect that n_0 is located in one of the ambiences in Φ_0, while n_1 will be in one of the ambiences in Φ_1. However, observe that if n_0 and n_1 are considered as slaves of the same group, their location information becomes more accurate as it can be deduced that both nodes will be located in one of the ambiences contained in the set $\Phi_{0,1} = \Phi_0 \cap \Phi_1$.

The same considerations apply when focusing on *location uncertainty*. In fact, on the one hand, considering n_0 and n_1 individually, the uncertainty on their position is $\log_2 |\Phi_0|$ and $\log_2 |\Phi_1|$, respectively, as defined in [31]. On the other hand, considering nodes as belonging to a group, uncertainty will be equal to $\log_2 |\Phi_{0,1}|$, where obviously $|\Phi_{0,1}| \leq \min\{|\Phi_0|, |\Phi_1|\}$. Therefore, it is evident that group mobility can be exploited to reduce location uncertainty.

However, since it is impossible to continuously achieve an updated picture of the current composition of groups, exploiting group mobility to obtain higher accuracy in object localization can result in location errors. In fact, it can happen that the current position of a node n is estimated as the position of the group which has just left. These errors can have dramatic effects on the application. The resulting implications will be addressed in Section V-B where we will analyze the tradeoff between location accuracy and location errors.

IV. Mobility management procedures

In this section we describe the basic operations needed to implement the OGM paradigm and discuss how they can be mapped into the MIPv6[5]. Then, in Section V we will analyze the effects of such a group management in terms of location accuracy and signaling cost.

[4] In the rest of this paper we will use equivalently the term items, objects and/or nodes.

[5] We assume in the following that the reader is familiar with MIPv6 operations.

Let us assume that a group consists of a master, n_0, and m slaves denoted as $n_1, ..., n_m$. Moreover, we denote the current care-of-address of a node n as $CoA(n)$.

The group master n_0 assigns an address of its home network $HN(n_0)$ to each slave. To this purpose, each node which is expected to be a group master is assigned several IPv6 addresses. Let $LA(n_i)$, with $i > 0$, represent the address assigned by n_0 to node n_i. Each slave n_i will provide $LA(n_i)$ as its current care-of-address to its home agent $HA(n_i)$, and will perform a binding to $HA(n_0)$ providing its current care-of-address $CoA(n_i)$.

In this way, if a node – the so called "*correspondent node*" – sends a packet to a slave n_i, the packet will reach the home network of n_i, $HN(n_i)$. Here the packet will be intercepted by the home agent $HA(n_i)$ and forwarded to the care-of-address it is aware of, i.e. $LA(n_i)$. In this way the packet will reach the home network of the group master $HN(n_0)$ where the packet, received by the home agent of the group master $HA(n_0)$, will be forwarded to the current care-of address of n_i, $CoA(n_i)$.

The proposed procedure allows to achieve a significant reduction of the signaling traffic generated to keep location information updated. Note, in fact, that when nodes of a group move a change their CoAs there is no need to inform the home agents of the slaves. Information must be updated in the home agent of the group master only.

Observe that in several application scenarios (especially, in logistics) there might be a large number of nodes in the same group with the same home agent. For example, suppose that $\Omega = \{n_1, n_2, ..., n_l\}$ is the set of slaves of the group with the same home agent $HA(n_1) = HA(n_2) = ... = HA(n_l)$. If this is the case, a *collective agent* is initialized which is responsible for keeping updated information about all nodes in Ω. The collective agent is a process initialized in the home network of the subset of nodes Ω. The collective agent acts as a proxy between the nodes in Ω and their home agent. One of the nodes in Ω will provide information about the current foreign network of the group to the collective agent which will send it to the home agent $HA(n_1)$. In this way, packets sent to nodes Ω will not pass through $HA(n_0)$, like it is the case for packets sent to other nodes in the group, before reaching their destination. Therefore, the cost of delivering data to nodes in Ω will decrease.

Nodes in Ω will update $HA(n_1)$ about their location instead of the home agent of the group master $HA(n_0)$. We will show that collective agents are convenient when the number of nodes in Ω is higher than a given threshold n^* which will be calculated in Section V.

In the rest of this section we will detail the mobility management procedures implementing the above policies.

A node n leaving the radio coverage of access point AP_1 and entering the radio coverage of a new access point, say AP_2 with the same access technology, will get a new care-of-address valid for the current foreign network. To this purpose, traditional stateless/stateful autoconfiguration procedures as defined in MIPv6 can be used [2].

Once the new CoA has been obtained, node n sends an update message to the context server (CS)[6] communicating its IPv6 home address, the address of its home agent $HA(n)$, its MAC address, its access technology, $\psi(n)$, the set of addresses it has been reserved by its home network $HN(n)$ and must assign as addresses to its slaves in case the node behaves as group master, as we will explain in the following.

Once the CS receives the update message, it must perform the following actions:

1) Update group and location information,
2) Evaluate location of nodes in the group.

These actions will be described below.

Update group and location information: To perform group management, the CS keeps track of the existing groups and of the movements of nodes within its area of interest.

If the node n sending the update message is part of an existing group, $\Gamma(n)$, the CS waits for a timeout[7] and then checks that its new position is consistent with the positions of the other nodes in the group. More specifically, the policy which will be utilized is that slaves with positions being inconsistent with the group master are removed from the group. To this purpose both the home agent of the group master and the interested slave are informed. The latter will then send a binding update to its home agent to provide it with its actual care-of-address.

Also, the CS controls if it is possible to merge the group of n to other groups or to individual nodes. To this purpose, observe that the group of n, $\Gamma(n)$, and group Γ_1 can be merged in the following two cases:

- All nodes in Γ_1 with the same access technology of n have recently left the old access point of n, AP_1, and joined the new one, AP_2, to which n is currently attached as well.
- In Γ_1 there are no nodes with access technology $\psi(n)$; however, the hypothesis that nodes of the two groups can be merged into a single group is consistent with the observation of their last h movements[8].

In the two above cases location information must be updated. To this purpose, one of the nodes in the group of n, $\Gamma(n)$ with access technology $\psi(n)$ is selected for sending a binding update to the home agent of the group master $HA(n_0)$. Observe that it is sufficient that the binding message contains information about the foreign subnet prefix of the new foreign network FN, which can be derived by the data inserted in standard binding messages. Indeed, according to IPv6 stateless address autoconfiguration, foreign subnet prefix

[6]Note that this interaction between the node and the CS is necessary for supporting context aware services, independently of the mobility management procedures executed to implement the OGM paradigm. Also observe that, using standard service discovery protocols such as UPnP [32], [33], a node entering a given area obtains information about the available CS and provides information about its characteristics and offered services.

[7]The use of a timeout in context servers as a mechanism to provide context-aware services has been widely proposed in the existing literature for different application scenarios. Furthermore, its optimal design has been in depth analyzed, such as in [34], where authors propose a cost-efficient design of the timer in such a way to reduce the delivery delay while coping with cost issues.

[8]Identification of the optimal value of h strongly depends on the specific application scenario. However, this is not a problem given that group merging will be performed by CS which is aware of the scenario.

and MAC address are enough to calculate the care-of address of any node. Therefore, $HA(n_0)$ can reconstruct the new care-of-address for all the nodes in the group $\Gamma(n)$ with access technology $\psi(n)$.

Finally, if a collective agent has been initialized for a set of nodes Ω including n, then one of the nodes in Ω will be selected to inform $HA(n_0)$ that all the nodes in Ω have moved to another location.

The case in which n was not part of a group can be dealt similarly. The obvious difference is that it is not necessary to perform control on the state of the group $\Gamma(n)$ given that $\Gamma(n)$ consists of node n only. A sketch of the flowchart of the procedures executed by network nodes and CS is reported in Figure 2.

Evaluate location of nodes in the group: In order to achieve more accurate information about the ambience where a node is located, the CS defines for each node z in the group, i.e., $z \in \Gamma(n)$, the set $\Phi(z) = C(AP(z))$, where $AP(z)$ denotes the access point providing coverage to node z whereas $C(AP)$ represents the set of ambiences covered by an access point AP. If nodes in $\Gamma(n)$ are in the same ambience, then it is obvious that they will be located in $[\cap_{z\in\Gamma(n)}\Phi(z)]$.

However, it is possible that some of the nodes left the group $\Gamma(n)$ and, therefore, the above estimation of the position of the nodes may be not correct. Accordingly, CS estimates whether it is convenient to achieve higher location accuracy at the risk of having errors in position estimation. To this purpose it uses the results of the analysis reported in Section V-B.

V. Analysis

In the following subsections we will derive an analytical framework for the evaluation of the impact of the use of OGM on the signaling overhead (Sections V-A) and the location errors and accuracy (Sections V-B).

A. Impact on signaling

In this section we evaluate the impact of exploiting object group mobility on the amount of signaling. In fact, in Section III we have discussed how object group mobility can help to reduce the amount of signaling generated for location update purposes. On the other hand, in Section IV we have noted that data traffic directed towards a slave node will pass through the HA of the group master before it is forwarded to the current foreign network. This is expected to cause longer delay as well as increased consumption of network resources. Accordingly, we will first evaluate the reduction in the amount of signaling needed for location update and, then, we will calculate the increase in the consumption of network resources needed to deliver a packet to a mobile node.

As usual in the most relevant literature in the field (e.g. [35]), in the following we assume that the time a node with communication technology ψ spends without needing to change its CoA is exponentially distributed with average $\bar{T}_\psi$. Accordingly, new location updates will be required with rate $\lambda_\psi^{(\mathrm{UP})} = 1/\bar{T}_\psi$.

Now suppose that at time t'' a group Γ_3 of nodes employing access technology ψ leaves the radio coverage of access point $AP_{(\mathrm{old})_\psi}$ and enters the radio coverage of another access point $AP_{(\mathrm{new})_\psi}$. Due to such a movement, nodes will likely need a new care-of-address. Note that the current group of nodes Γ_3 is different from what the system recognizes as such. In fact, information about the group was last updated at time t' when the nodes entered the radio coverage of $AP_{(\mathrm{old})_\psi}$. We denote as Γ_1 the set of nodes with access technology ψ composing the group at time t' and as Γ_2 the subset of nodes in Γ_3 that were part of the group Γ_1 also at time t', i.e., $\Gamma_2 = \Gamma_3 \cap \Gamma_1$. Using traditional MIPv6 solutions each of the Γ_3 nodes will be required to take a new CoA and issue a binding message towards its home agent. Now let us define as Ω_1, Ω_2, and Ω_3 the subsets of nodes in Γ_1, Γ_2, and Γ_3, respectively, with the same home agent HA^*. Also let us define Λ_1, Λ_2, and Λ_3 the remaining nodes in groups Γ_1, Γ_2, and Γ_3, respectively, that is $\Lambda_1 = \Gamma_1 - \Omega_1$, $\Lambda_2 = \Gamma_2 - \Omega_2$, and $\Lambda_3 = \Gamma_3 - \Omega_3$. Furthermore, for the sake of notation simplicity, let Y_1, Y_2, and Y_3 be the random variables representing the number of nodes in the subsets Ω_1, Ω_2, and Ω_3, respectively; and Z_1, Z_2, and Z_3 be the random variables representing the number of nodes in the subsets Λ_1, Λ_2, and Λ_3, respectively.

To exploit object group mobility we need one binding message for the group, one binding message for each of the nodes in $\Lambda_3 - \Lambda_2$, and a number V_{LU} of binding messages depending on the number Y_3 of nodes in the group at time t'' with the same home agent HA^*. We expect that, if the current number of nodes with the same home agent Y_3 is lower than the threshold n^* – where value of n^* is calculated in the following[9] – then we will need a binding message for each of the $|\Omega_3 - \Omega_2|$ nodes with home agent HA^* that joined the group after time t'; to this regard, note that $(Y_3 - Y_2)$ is likely to be zero as composition of groups is not expected to change frequently. In the opposite case, we will need only one binding message sent to HA^* for all the nodes in Ω_3.

Accordingly, the value of V_{LU} is given by

$$V_{LU} = \begin{cases} Y_3 - Y_2, & \text{if } Y_3 < n^* \\ 1, & \text{if } Y_3 \geq n^* \end{cases} \tag{1}$$

It follows that, by exploiting object group mobility, the decrease in the cost of signaling generated for location update purposes is given by:

$$\Delta_{\mathrm{LU}} = \lambda_\psi^{(\mathrm{UP})} c^{(\mathrm{LU})} (Z_2 + Y_3 - 1 - V_{LU}) \tag{2}$$

where $\lambda_\psi^{(\mathrm{UP})} = \frac{1}{T_\psi^{(\mathrm{UP})}}$ and $T_\psi^{(\mathrm{UP})}$ is the average time spent by the group using technology ψ within the radio coverage of the same access point, and $c^{(\mathrm{LU})}$ represents the average cost of a binding message.

The average value of Δ_{LU} is given by

$$E\{\Delta_{\mathrm{LU}}\} = \lambda_\psi^{(\mathrm{UP})} c^{(\mathrm{LU})} \Big[E\{Z_2 - 1 + Y_2 | Y_3 < n^*\} p(Y_3 < n^*) + E\{Z_2 - 2 + Y_3 | Y_3 \geq n^*\} p(Y_3 \geq n^*) \Big] \tag{3}$$

[9]Here we assume that there is only one subgroup of nodes with the same home agent

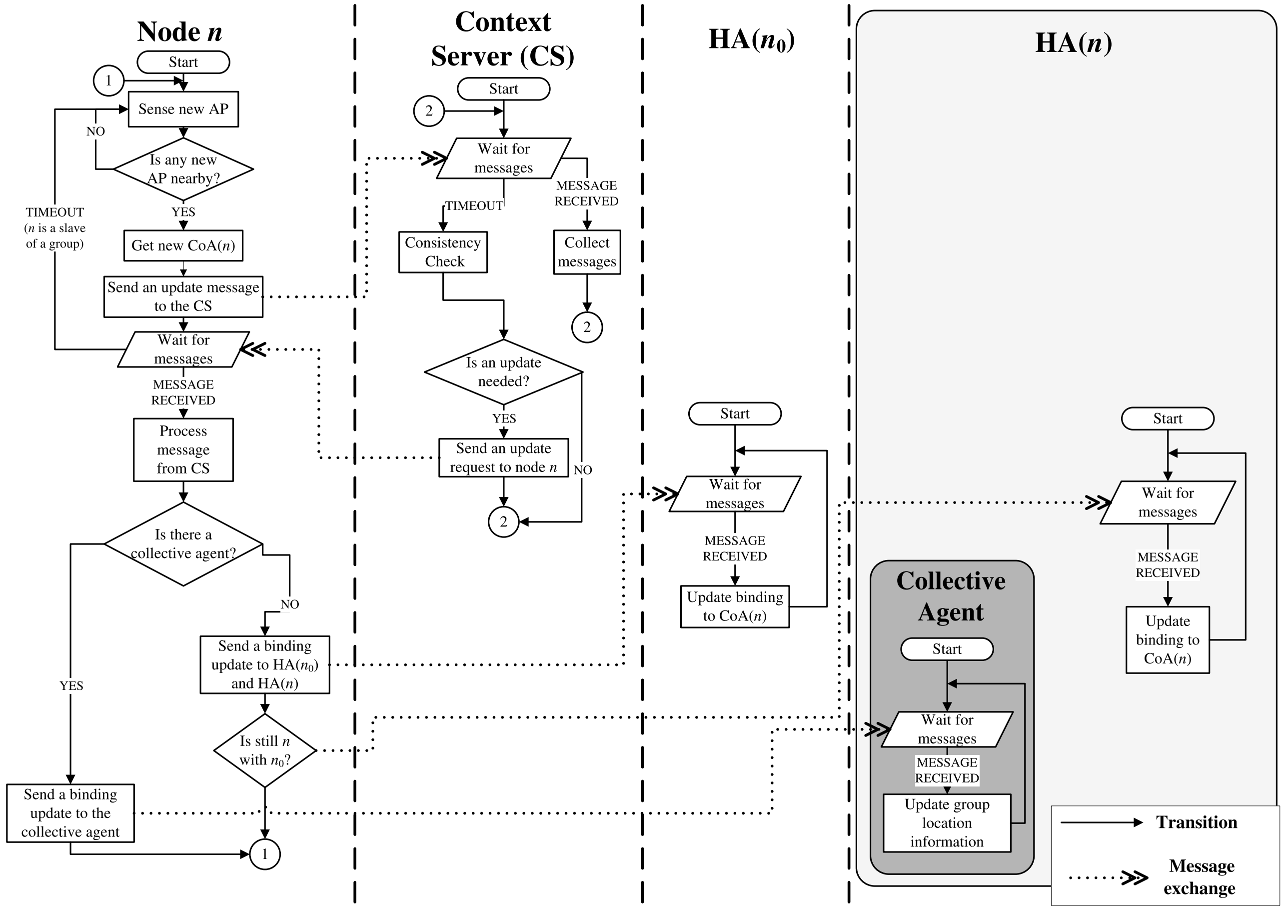


Fig. 2. Flowchart of OGM procedures.

If we assume that nodes with access technology ψ and home agent HA^* join the group according to an exponential process with rate λ_ψ^* and that each of these nodes leaves the group according to an exponential process with rate μ_ψ^*, then the probability distribution of Y_3 can be calculated as the steady state probability of a $M/M/\infty$ random process:

$$p(Y_3 = n) = \left(\rho_\psi^*\right)^n \cdot e^{-\rho_\psi^*}/n! \tag{4}$$

where $\rho_\psi^* = \lambda_\psi^*/\mu_\psi^*$. Therefore,

$$p(Y_3 < n^*) = \sum_{n=0}^{n^*-1} \left(\rho_\psi^*\right)^n \cdot e^{-\rho_\psi^*}/n! \tag{5}$$

and $p(Y_3 \geq n^*) = 1 - p(Y_3 < n^*)$.

Now we evaluate the first expected value in eq. (3), i.e. $E\{Z_2 - 1 + Y_2 | Y_3 < n^*\}$. It is easy to show that

$$E\{Z_2 - 1 + Y_2 | Y_3 < n^*\} = E\{Z_2\} - 1 + E\{Y_2 | Y_3 < n^*\} \tag{6}$$

In order to calculate the average value of Z_2 we apply the theorem of the total probability, so that we can write

$$E\{Z_2\} = \sum_{n=0}^{\infty} E\{Z_2 | Z_1 = n\} p(Z_1 = n) \tag{7}$$

If we assume that nodes with access technology ψ and home agent different from HA^* join the group with rate λ_ψ and that each of these nodes leaves the group with rate μ_ψ, then the probability distribution of Z_1 can be calculated as follows

$$p(Z_1 = n) = \left(\rho_\psi\right)^n \cdot e^{-\rho_\psi}/n! \tag{8}$$

where $\rho_\psi = \lambda_\psi/\mu_\psi$; on the contrary Z_2 can be seen as the value at time t'' taken by a pure death random process that at time t' was in state Z_1. Accordingly, we can rewrite eq. (7) as follows:

$$E\{Z_2\} = \sum_{n=0}^{\infty} \Bigg[p(Z_1 = n) \cdot \int_0^{\infty} E\{Z_2 | Z_1 = n, t'' - t' = \tau\} f_{T_{\mathrm{UP}}}(\tau) d\tau \Bigg] \tag{9}$$

where $f_{T_{\mathrm{UP}}}(\tau)$ is the probability density function of the random variable T_{UP} representing the time spent by the group master within the radio coverage of the same access point. If we assume that T_{UP} is distributed exponentially with average $1/\lambda_M^{(\mathrm{UP})}$, then it is easy to show that the average value of the random variable Z_2 can be calculated as

$$E\{Z_2\} = \lambda_M^{(\mathrm{UP})} \lambda_\psi / \left[\mu_\psi \left(\mu_\psi + \lambda_M^{(\mathrm{UP})} \right) \right] \tag{10}$$

In eq. (6), we also need the average value of Y_2 given that $Y_3 < n^*$. To evaluate such term observe that

TABLE I
RELEVANT PARAMETERS

Name	Description
$\psi(AP)$	the access technology used by AP
$C(AP)$	the set of ambiences covered by AP
$\psi(n)$	the access technology of node n
$HN(n)$	the home network of node n
$HA(n)$	the home agent associated to node n
$LA(n)$	the address assigned by a GM n_0 to a node n
$CoA(n)$	the care-of-address of node n
n^*	the threshold value in number of grouped nodes above which the use of a collective agent is convenient
$\lambda_\psi^{(\mathrm{UP})} = 1/\bar{T}_\psi$	the rate associated to the time spent by the group using technology ψ within the radio coverage of the same access point
V_{LU}	the number of binding messages to be sent to the same home agent
Δ_{LU}	the decrease in the bandwidth resources achieved by exploiting OGM
$c^{(\mathrm{LU})}$	the average amount of bandwidth resources consumed for each binding message
λ_ψ	the group join rate
μ_ψ	the group leave rate
$\lambda_M^{(\mathrm{UP})} = 1/T_{\mathrm{UP}}$	the rate associated to the time spent by the GM within the radio coverage of the same access point
λ_D	the rate at which packets that must be delivered to a mobile node are generated
c_D	the average increase in signaling cost due to the fact that packets that must be delivered to a slave will pass through the GM's home agent HA_{GM}.

$$E\{Y_2|Y_3 < n^*\} = \frac{1}{p(Y_3 < n^*)} \sum_{n=0}^{n^*-1} p(Y_3 = n) \cdot E\{Y_2|Y_3 = n\} \tag{11}$$

It can be shown that

$$E\{Y_2|Y_3 = n\} = F_1(n, \lambda_M^{(\mathrm{UP})}, \mu_\psi^*, \rho_\psi^*) + F_2(n, \lambda_M^{(\mathrm{UP})}, \mu_\psi^*, \rho_\psi^*) \tag{12}$$

where

$$F_1(n, \lambda_M^{(\mathrm{UP})}, \mu_\psi^*, \rho_\psi^*) = (n - \rho_\psi^*) \left(1 - e^{-\frac{\lambda_M^{(\mathrm{UP})}}{\mu_\psi^*} \log\left(\frac{\rho_\psi^*}{\rho_\psi^* - n}\right)}\right) \tag{13}$$

and

$$F_2(n, \lambda_M^{(\mathrm{UP})}, \mu_\psi^*, \rho_\psi^*) = \frac{\lambda_M^{(\mathrm{UP})} \rho_\psi^*}{\lambda_M^{(\mathrm{UP})} + \mu_\psi^*} \Bigg(1 - e^{-\frac{\lambda_M^{(\mathrm{UP})} + \mu_\psi^*}{\mu_\psi^*} \log\left(\frac{\rho_\psi^*}{\rho_\psi^* - n}\right)}\Bigg) \tag{14}$$

and $\lambda_M^{(\mathrm{UP})}$ is the handover rate of the master. The second expected value in eq. (3) can be easily calculated as:

$$E\{Y_3 + Z_2 - 2|Y_3 \geq n^*\} = \frac{1}{p(Y_3 \geq n^*)} \Bigg[\rho_\psi^* - \sum_{n=1}^{n^*-1} \frac{(\rho_\psi^*)^n}{(n-1)!} e^{-\rho_\psi^*}\Bigg] + E\{Z_2\} - 2 \tag{15}$$

where $E\{Z_2\}$ has been calculated in eq. (10).

However, as we already pointed out, use of OGM can cause an increase in the cost incurred to deliver data packets to mobile nodes. In fact, packets sent by a correspondent node will pass through the home agent of the group master before they reach group slaves. Similarly to what we have discussed before, it can be shown that the average value of the difference between the cost for data delivery when we exploit OGM and when traditional mobility management schemes is used can be calculated as

$$E\{\Delta_D\} = \lambda_D c_D \left[E\{Z_3\} + E\{V_D\}\right] \tag{16}$$

where:

- λ_D is the average rate at which packets that must be delivered to a mobile node are generated.
- c_D is the average increase in cost due to the fact that packets that must be delivered to a slave in the group will pass through the group master home agent HA_{GM}.
- V_D is a random variable defined as follows:

$$V_D = \begin{cases} Y_3, & \text{if } Y_3 < n^* \\ 0, & \text{if } Y \geq n^* \end{cases} \tag{17}$$

To solve eq. (16), it can be easily shown that $E\{Z_3\} = \rho_\psi$ and

$$E\{V_D\} = E\{Y_3|Y_3 < n^*\} = \frac{e^{-\rho_\psi^*}}{p(Y_3 < n^*)} \sum_{k=1}^{n^*-1} \frac{(\rho_\psi^*)^k}{(k-1)!} \tag{18}$$

Finally, we want to evaluate the most appropriate value for n^*. To this purpose note that the use of a collective agent is convenient when the decrease in signaling cost achieved by using a collective agent is higher than the increase in cost required to send a binding update to the home agent HA^*. This occurs when:

$$\lambda_\psi^{(\mathrm{UP})} c^{(\mathrm{LU})} < Y_3 \lambda_D c_D \tag{19}$$

and therefore:

$$n^* = \frac{1}{1 - (\lambda_D c_D)/(\lambda_\psi^{\mathrm{UP}} c^{\mathrm{LU}})} \tag{20}$$

In Section VI we will investigate the variations of n^* for different network configurations and mobile scenarios.

B. Impact on location accuracy and location errors

In order to conveniently trade a decrease in uncertainty with the possibility of performing location errors, we consider the two competing terms for a certain node n_k:

- $H(X_k)$ is the entropy (which is a measure of uncertainty [31]) of the random variable X_k representing the current ambience where node n_k is located;
- $\Pr\{\text{Error}\}$ is the probability of doing an error in locating node n_k.

Observe that, if group mobility is not taken into account, the error probability is equal to zero whereas location uncertainty is $H(X_k) = \log_2 |\Phi_k|$, where Φ_k represents the set of ambiences where node n_k can be located. Note that if node n_k is reachable by one of the access points, say AP_k, then Φ_k includes the ambience X_k where node n_k is currently located; if node n_k is not reachable by any AP, then Φ_k is the set of ambiences that are not covered by any access point employing technology $\psi(n_k)$.

We start by evaluating the error probability $\Pr\{\text{Error}\}$.

Suppose that a group Γ is formed around the group master n_0, that is $\Gamma = \{n_0, n_1, ..., n_k\}$.

Here we are assuming again that these $(k+1)$ nodes can exploit different communication technologies $\psi_i, \psi_z, \ldots, \psi_k$. Also let us suppose that t_0 is the last time instant when the existence of the group was verified. The probability of making an error at time t, with $t \geq t_0$, in the estimation of the position of n_k can be evaluated as the probability that the node has left the group in the time interval $]t_0, t]$. Let T_k be the random variable representing the duration of the time interval during which node n_k (which we suppose is a slave) is aggregated to its master n_0. We assume that T_k is exponentially distributed with rate μ_k. Accordingly, the probability of error is

$$\Pr\{\text{Error}\} = \left(1 - e^{-\mu_k(t-t_0)}\right)\left(\frac{|\Phi_k| - |\cap_{i=0}^{k} \Phi_i|}{|\Phi_k|}\right) \quad (21)$$

To explain eq. (21), note that by exploiting the group mobility concept we guess that node n_k is located in one of the ambiences belonging to the intersection between all sets Φ_i, for $i \leq k$, i.e., we assume that $X_k \in \left(\cap_{i=0}^{k} \Phi_i\right)$. If node n_k is not part of the group anymore, then it is located in any of the ambiences included in Φ_k with equal probability. Accordingly, the probability that by exploiting group mobility we incur in erroneous localization is given by the probability that node n_k left the group, which is given by the first term of the product in the right hand side of eq. (21), multiplied by the probability that node n_k moved outside the intersection $\left(\cap_{i=0}^{k} \Phi_i\right)$, which is given by the second term of the product in the right hand side of eq. (21).

In order to evaluate the uncertainty on X_k considering that n_k was part of a group mastered by n_0 together with n_1, n_2, ..., n_{k-1}, let us define Φ_i the set of ambiences where the generic node n_i can be located.

Accordingly, we are interested in evaluating

$$\begin{aligned} &H(X_k|X_k \in \Phi_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) = \\ &\quad = -\sum_{X_k \in \Phi_k} p\left(X_k = x_k | X_k \in \Phi_k, ..., X_0 \in \Phi_0\right) \\ &\quad \cdot \log_2 p\left(X_k = x_k | X_k \in \Phi_k, ..., X_0 \in \Phi_0\right) \end{aligned} \quad (22)$$

The probabilities in eq. (22) can be calculated as follows:

$$\begin{aligned} &p(X_k = x_k | X_k \in \Phi_k, ..., X_0 \in \Phi_0) = \\ &\quad = \begin{cases} 0, & \text{if } x_k \notin \Phi_k \\ \frac{p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0)}{p(X_k \in \Phi_k, ..., X_0 \in \Phi_0)}, & \text{if } x_k \in \Phi_k \end{cases} \end{aligned} \quad (23)$$

In the above equation we need the probabilities $p\left(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0\right)$ and $p\left(X_k \in \Phi_k, ..., X_0 \in \Phi_0\right)$. By applying the theorem of the total probability, we can calculate the former as follows:

$$\begin{aligned} &p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) = \\ &\quad = \sum_{x_0 \in \Phi_0} \cdot \sum_{x_1 \in \Phi_1} \cdots \\ &\quad \cdot \sum_{x_{k-1} \in \Phi_{k-1}} p(X_k = x_k, X_{k-1} = x_{k-1}, ..., X_0 = x_0) \end{aligned} \quad (24)$$

If we refer the position of each node in the group to the position of the group master n_0, the probability in eq. (24) can be calculated as:

$$\begin{aligned} &p(X_k = x_k, X_{k-1} = x_{k-1}, ..., X_0 = x_0) = \\ &\quad = p(X_k = x_k | X_0 = x_0) \ldots p(X_1 = x_1 | X_0 = x_0) \\ &\quad \cdot p(X_0 = x_0) \end{aligned} \quad (25)$$

By replacing eq. (25) in eq. (24) we obtain

$$\begin{aligned} &p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) = \\ &\quad = \sum_{x_0 \in \Phi_0} p(X_0 = x_0) \cdot p(X_k = x_k | X_0 = x_0) \\ &\quad \cdot \sum_{x_1 \in \Phi_1} p(X_1 = x_1 | X_0 = x_0) \cdots \\ &\quad \cdot \sum_{x_{k-1} \in \Phi_{k-1}} p(X_{k-1} = x_{k-1} | X_0 = x_0) \end{aligned} \quad (26)$$

Observe that at time t the generic conditioned probability needed in eq. (26) can be calculated as follows:

$$\begin{aligned} &p(X_i = x_i | X_0 = x_0) = \\ &\quad = \begin{cases} e^{-\mu_i \tau} + (1 - e^{-\mu_i \tau})/|\Phi_i|, & \text{if } x_i = x_0 \\ (1 - e^{-\mu_i \tau})/|\Phi_i|, & \text{if } x_i \neq x_0 \end{cases} \end{aligned} \quad (27)$$

where $\tau = (t - t_0)$.

Using eq. (27), it is easy to show that

$$\sum_{x_i \in \Phi_i} p(X_i = x_i | X_0 = x_0) = \begin{cases} 1 - e^{-\mu_i \tau}, & \text{if } x_0 \notin \Phi_i \\ 1, & \text{if } x_0 \in \Phi_i \end{cases} \quad (28)$$

Accordingly, if we define the function $\phi_i(x, \Phi)$ as follows:

$$\phi_i(x, \Phi) = \begin{cases} 1 - e^{-\mu_i \tau}, & \text{if } x \notin \Phi \\ 1, & \text{if } x \in \Phi \end{cases} \quad (29)$$

then, we can rewrite eq. (26) as

$$p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) = \\ = \sum_{x_0 \in \Phi_0} p(X_0 = x_0) p(X_k = x_k | X_0 = x_0) \phi_1(x_0, \Phi_1) \\ \cdot \phi_2(x_0, \Phi_2) \cdots \phi_{k-1}(x_0, \Phi_{k-1}) \quad (30)$$

The probability $p(X_0 = x_0)$ is, in general, independent of the specific value of x_0; therefore, we denote it as p_0 and we can rewrite eq. (30) as

$$p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) = \\ = p_0 \sum_{x_0 \in \Phi_0} p(X_k = x_k | X_0 = x_0) \phi_1(x_0, \Phi_1) \cdots \\ \cdots \phi_{k-1}(x_0, \Phi_{k-1}) \quad (31)$$

Analogously, we can calculate the probability $p(X_k \in \Phi_k, ..., X_0 \in \Phi_0)$ used in eq. (23) as

$$p(X_k \in \Phi_k, ..., X_0 \in \Phi_0) = \\ = \sum_{x_k \in \Phi_k} p(X_k = x_k, X_{k-1} \in \Phi_{k-1}, ..., X_0 \in \Phi_0) \quad (32)$$

where the terms in the sum of eq. (32) have been calculated as shown in eq. (31).

VI. Simulation Results

Objective of this section is twofold. In fact, on the one hand we want to assess the accuracy of the analytical framework developed in Section V. On the other hand, we want to evaluate the performance improvement that can be obtained by exploiting OGM as proposed in Section IV. In this context we compare the performance of our approach to those of mechanisms exploiting OGM.

To this purpose, we have run a large number of simulations focusing on two scenarios:

- **Logistics:** vehicles move throughout a limited area and pick some items up so as to deliver them to their destination.
- **Personal items:** humans move in the same area considered in the previous scenario and carry a certain number of smart objects (e.g., smartphones, tablets, MP3 readers, laptops, etc) with them. The type of devices and their number depend on the activity humans do.

The above scenarios will be the focus of Sections VI-A and VI-B, respectively.

For both cases we have developed a Java simulator which is based on the models proposed in [36] for the logistics scenario and in [37] for the personal items scenario.

A. Logistics

We consider a rectangular 6×2 km^2 area with a Manhattan-like grid road topology consisting of 100 streets. In the above area there are n_{GM} vehicles moving according to the Manhattan mobility model whose mobility traces are generated by the MobiSim simulator [36]. Vehicles can for example be pony expresses which take over objects, carry and deliver them to customers randomly located on the map. Vehicles will act as *group masters* (GM) of the group they form together with the objects they carry. Say n_C the number of customers. Each time a vehicle arrives at the premises of a customer, it delivers each of the carried objects with a given probability, P_{Delivery}. In our simulations we assume $n_{GM} = 100$ and $n_C = 100$.

We further assume that each object is equipped with one or more wireless interfaces in order to access Internet through the interest access network.

TABLE II
Wireless Interfaces Available in the personal items

Item	ψ_0	ψ_1	ψ_2	ψ_3
Smartphone	×	×	×	×
Laptop		×	×	×
Tablet	×	×	×	
MP3 Player			×	
Sensor				×

The access network consists of several, say n_{AP}, access points providing access to the Internet to GMs and carried items. To evaluate the impact of the number of access points deployed on the map, we consider both metropolitan scenarios, e.g. cities such as Washington, and rural scenarios, e.g. small cities such as San Gimignano in Tuscany (Italy). For example, according to [38] up to 500 base stations are deployed in an area of approximately 12 km^2 in size in the city of Washington, while in the same area, only 10 base stations are deployed in San Gimignano. Accordingly, we will consider n_{AP} in the range $[10, 500]$.

In our simulations we suppose that access points are randomly deployed on the 12 km^2 map and are equipped with a wireless interface. More specifically, we will consider four different types of wireless technologies, which we denote as ψ_0, ψ_1, ψ_2 and ψ_3, characterized by radio coverage equal to 2000 m, 300 m, 100 m and 10 m, which are representative of cellular base stations (cell and microcells), wireless LANs, and wireless PANs, respectively.

In order to evaluate the impact of OGM on network performance we suppose that a percentage of the carried objects do not perform grouping with other objects, and act individually both for accessing the network and for location updates. In fact, it is reasonable that some objects are configured in such a way that they do not join groups (for privacy and/or security reasons, for example). We call P_{group} the probability that an object is configured to join groups. In the following we will consider three different values of P_{group}, that is $P_{\text{group}} = 0$ (Case A), $P_{\text{group}} = 0.2$ (Case B), and $P_{\text{group}} = 0.8$ (Case C).

We start by validating the accuracy of the expressions of the error probability and the uncertainty given in eqs. (21) and (22). More specifically we will study the error probability and the uncertainty as a function of the product $\mu_k(t - t_0) = \mu_k\tau$. In order to modify the value of this product, we change P_{Delivery}. In fact, the parameter μ_k, i.e., the rate with which a node is aggregated to its GM is proportional to the probability that the GM delivers the object.

In Figures 3 and 4 we compare the error probability $\Pr\{\text{Error}\}$ and the average uncertainty obtained analytically and by simulations versus $\mu_k\tau$.

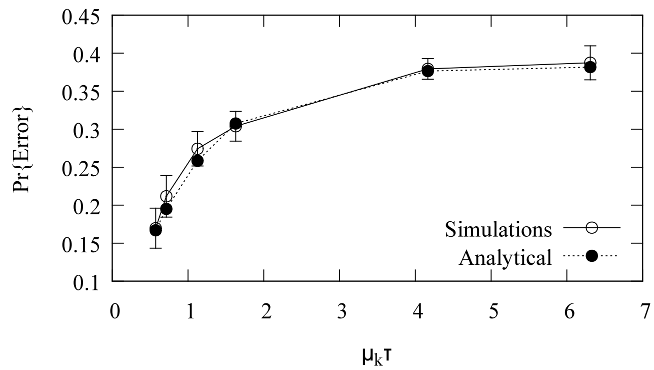


Fig. 3. Error probability versus the product $\mu_k \tau$.

In both figures we observe the good matching between analytical and simulation results. Also, as expected, both the error probability and the uncertainty increase with $\mu_k \tau$.

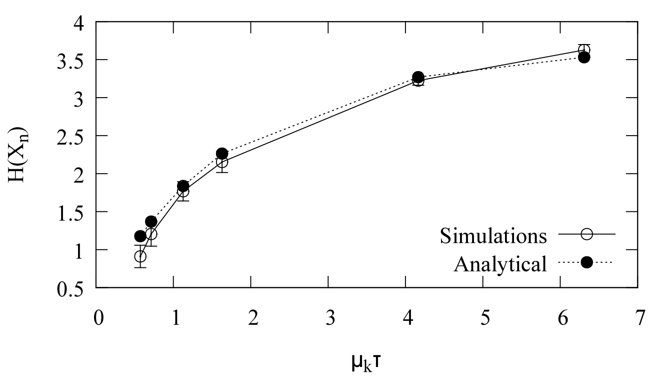


Fig. 4. Entropy versus the product $\mu_k \tau$.

Now we evaluate the performance achieved by exploiting the OGM concept. In the upper plot of Figure 5 the error probability $\Pr\{\mathrm{Error}\}$ is plotted as a function of n_{AP}. Note that the error probability decreases as n_{AP} increases. In fact, when a high number of APs are deployed, the simulation area is densely covered; hence, for both slaves and group masters, it is easier to get access to the network and update their position, which results in a decrease in location errors.

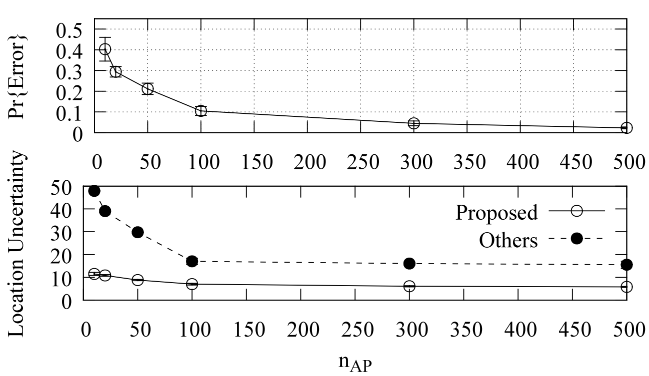


Fig. 5. Location error and location uncertainty versus the AP number (n_{AP}) in the logistics scenario.

Also, Figure 5 shows the average uncertainty on the location of nodes. As expected, the higher the number of access points, the lower the uncertainty is. In fact, when the density of access points is high, information at the home and collective agents is more accurate and uncertainty is reduced. For the sake of comparison in the same figure we show the uncertainty obtained by using NEMO- and MTC-like solutions which do not exploit nodes heterogeneity to increase location accuracy.

Figure 6 shows the average number of messages generated for location updates. Note that the signaling traffic can be significantly reduced by exploiting the OGM mechanisms. In fact, the average number of messages exchanged to keep the location information updated decreases as the percentage of grouped nodes increases (Cases B and C). Note that in Case C, the number of location updates generated by grouped nodes is considerably lower than in case of ungrouped devices.

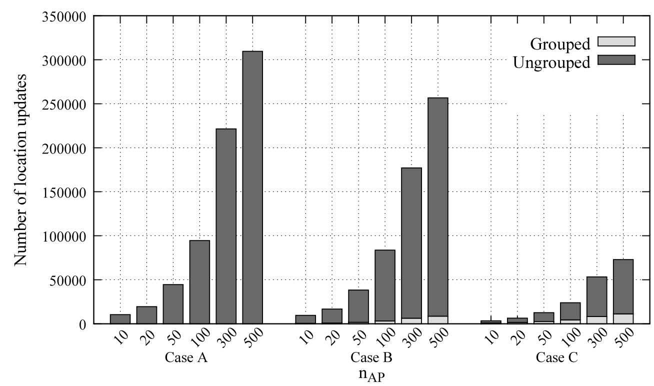


Fig. 6. Classification of location updates performed by grouped and ungrouped devices in the logistics scenario.

Finally, in Figure 7 we represent the value of n^* calculated in eq. (20) as a function of the product $k\lambda_D$ for different values of $\lambda_\psi^{(\mathrm{UP})}$, where $k = c_D/c^{LU}$. As expected, the optimal value of n^* increases as the product $k\lambda_D$ increases. Note that the values of the parameter $\lambda_\psi^{(\mathrm{UP})}$ have been obtained through simulations assuming $n_{AP} = 50$ and 300. The shaded areas show the feasible regions for each case (n_{AP} =50 and 300) where the use of a collective agent is convenient as the decrease in the number of location updates is higher than the increase in the signaling cost. In fact, an increase in the product $k\lambda_D$ causes an increase in the signaling cost which has to be traded-off with the reduction in the number of location updates achieved by exploiting OGM procedures.

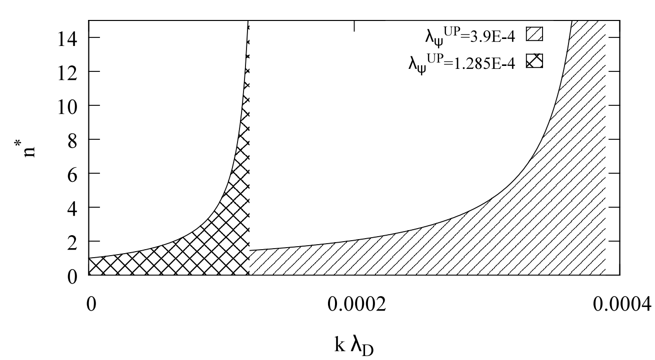


Fig. 7. Value of the variable n^* in the logistics scenario as a function of the product $k\lambda_D$ for different values of $\lambda_\psi^{(\mathrm{UP})}$.

B. Personal items

In this scenario GMs are humans moving throughout the area of interest with their smart items. In [37] it is investigated what kind of items people carry on depending on their current activity, e.g., when they go to the gym, they carry their MP3 reader and their heart rate sensor with higher probability than in the case they go to work. Accordingly, in our simulations we have defined different profiles (e.g., sportsman, businessman, tourist, etc..), we have randomly assigned a single profile to each of the n_{GM} humans and generated the objects composing the group on the base of the distributions given in [37]. Furthermore, we have assumed that the wireless interfaces available at each of the considered smart objects are those reported in Table II.

Figure 8 shows the average number of messages generated for location updates. Observe that, in case of the personal items scenario the number of location updates is smaller than in case of Scenario 1 due to the lower velocity of the carriers. Also, differently from the case of Scenario 1, it is evident that in Figure 8 the number of location updates required in the grouped and ungrouped cases are comparable. This is because of the smaller number of group members in Scenario 2.

In Figure 9, the error probability $\Pr\{\text{Error}\}$ and the average uncertainty on the location of nodes are plotted as a function of n_{AP}. Also in this case, in the same figure we show the uncertainty obtained by using NEMO- and MTC-like solutions.

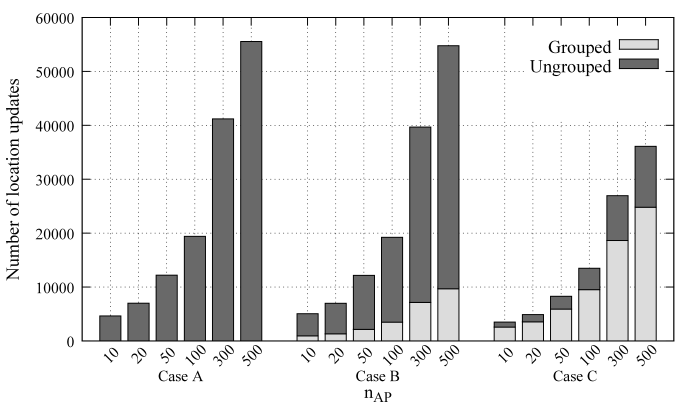


Fig. 8. Classification of location updates performed by grouped and ungrouped devices in the personal items scenario.

Finally, the value of n^* is plotted in Figure 10 as a function of the product $k\lambda_D$ for different values of $\lambda_\psi^{(\mathrm{UP})}$. As for the logistics scenario, an increase in the product $k\lambda_D$ causes an increase of the optimal value of n^*. The shaded areas show the feasible regions for each scenario where the use of a collective agent is convenient as the decrease in the number of location updates is higher than the increase in the signaling cost. Note that the different ranges of $k\lambda_D$ in Scenario 1 and 2, are due to the different $\lambda_\psi^{(\mathrm{UP})}$ values related to the carriers' velocity.

Simulation results obtained in this scenario confirm the trends highlighted for the logistics scenario discussed in Section VI-A.

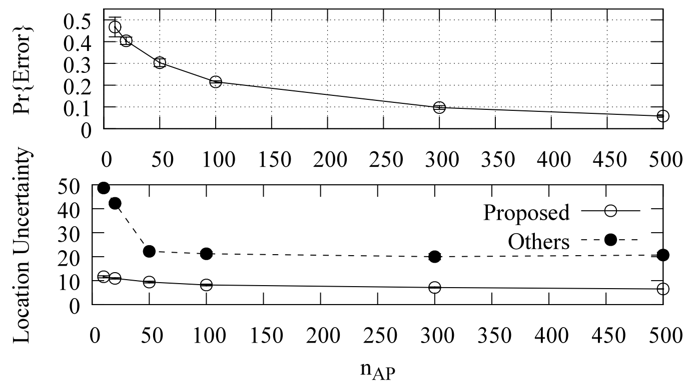


Fig. 9. Location error and uncertainty versus the AP number n_{AP} in the personal items scenario.

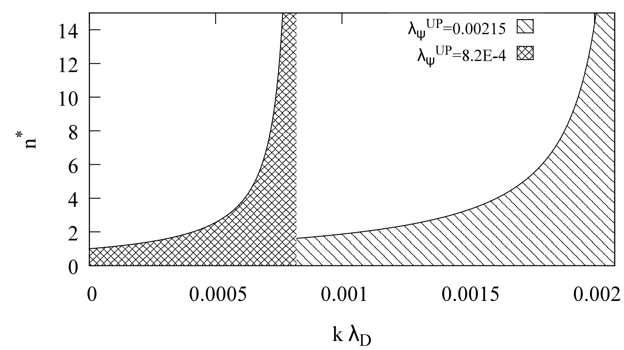


Fig. 10. Value of the variable n^* in the personal items scenario as a function of the product $k\lambda_D$ for different values of $\lambda_\psi^{(\mathrm{UP})}$.

VII. Conclusions

In this paper we presented an analysis of object group localization in IoT scenarios. We showed how, in IoT scenarios, object group mobility (OGM) can be exploited to increase location accuracy and reduce the consumption of network resources while maintaining compatibility with mobile IPv6 and its features. We provided basic mobility management procedures to exploit OGM in IoT scenarios. An analytical framework for the evaluation of the performance improvement which can be obtained by exploiting OGM has been presented. The proposed analytical framework has been validated through simulations; moreover the improvement in terms of both signaling efficiency and location accuracy achieved when OGM is exploited are discussed.

References

[1] D. Evans. The Internet of Things: How the Next Evolution of the Internet Is Changing Everything. *Cisco IBSG – White Paper*. April 2011.

[2] D. Johnson, C. Perkins and J. Arkko. Mobility support in IPv6. RFC, http://www.ietf.org/rfc/rfc3775.txt Jun. 2004.

[3] NEMO *http://tools.ietf.org/html/rfc3963*

[4] http://www.nautilus6.org/

[5] http://www.cisco.com/c/en/us/products/ios-nx-os-software/mobile-networks/index.html

[6] K. Lan and E. Perera and H. Pet and C. Dwertmann and L. Libman, M. Hassan. MOBNET: the design and implementation of a network mobility testbed for NEMO protocol. *Proc. of 14th IEEE Workshop on Local and Metropolitan Area Networks (LANMAN)*. September 2005.

[7] Y.-S. Chen, C.-S. Hsu, and C.-H. Cheng. Network mobility protocol for vehicular ad hoc networks. *Wiley International Journal of Communication Systems.* March 2013. doi: 10.1002/dac.2525

[8] Y.S. Chen, K. L. Chiu, K. L. Wu, T. Y. Juang. A cross-layer partner-assisted handoff scheme for hierarchical mobile IPv6 in IEEE 802.16e systems. *Proc. of IEEE WCNC*. March 2007. Hong Kong, China.

[9] T. Arnold, W. Lloyd,J. Zhao. IP address passing for VANETs. *Proc. of IEEE PERCOM*. March 2008. Hong Kong, China.

[10] R. Baldessari, A. Festag, J. Abeille. NEMO meets VANET: A Deployability Analysis of Network Mobility in Vehicular Communication. *Proc. of ITST 2007*. June 2007.

[11] P. K Chowdhury, M. Atiquzzaman, and W. Ivancic. SINEMO: an IP-diversity based approach for network mobility in space. *Proc. of Second IEEE Int. Conference on Space Mission Challenges for Information Technology*. July 2006.

[12] H.-L. Fu, P. Lin, H. Yue, G.-M. Huang. Group Mobility Management for Large-Scale Machine-to-Machine Mobile Networking. *IEEE Trans. on Vehicular Networks*. Vol. 63, No. 3. March 2014.

[13] T. Taleb and A. Kunz. Machine Type Communications in 3GPP Networks: Potential, Challenges, and Solutions. *IEEE Communications Magazine*. Vol. 50, No. 3. March 2012

[14] `http://www.iot-a.eu/`

[15] F. Carrez *et al.* Internet of Things - Architecture - Final architectural reference model for the IoT. *Internet of Things - Architecture, Deliverable 1.5 - v3.0*. July 2013.

[16] H Sundmaeker, P Guillemin, P Friess, S Woelffle'. Vision and challenges for realising the Internet of Things. *Cluster of European Research projects on the Internet of things*. March 2010.

[17] IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals RFC 4919. *http://datatracker.ietf.org/doc/rfc4919/*

[18] IPv6 http://ipv6.com/articles/applications/Using-RFID-and-IPv6.htm

[19] S. Dominikus, H. Gross, M. Aigner, S. Kraxberger. Low-cost RFID Tags as IPv6 Nodes in the Internet of Things. *Cryptology and Information Security Series, Radio Frequency Identification System Security, Vol. 6*. 2012.

[20] H. Schulzrinne, X. Wu and S. Sidiroglou Ubiquitous computing in Home Networks. *IEEE Communication Magazine*. Vol. 41 , No. 11. Nov. 2003.

[21] Y. Oh, J. Han and W. Woo. A Context management architecture for large-scale smart environments. *IEEE Communication Magazine*. Vol. 48 , No. 3. Mar. 2010.

[22] E. Welbourne, L. Battle, G. Cole, K. Gould, K. Rector, S. Raymer, M. Balazinska and G. Borriello. Building the Internet of Things Using RFID: The RFID Ecosystem Experience. *IEEE Internet Computing*. Vol. 13 , No. 3 May 2009.

[23] A. Heil, M. Knoll and T. Weis. The Internet of things-Context-based Device Federations. *IEEE HICSS* Jan. 2007.

[24] Freescale. Freescale, Oracle address industry for IoT Standards. *M2M Magazine*. September 2013.

[25] A. Mei, J. Stefa. SWIM: A simple model to generate small mobile worlds. *IEEE Infocom 2009.* Apr. 2009.

[26] A. Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass and J. Scott. Impact of human mobility on the design of opportunistic forwarding algorithms. *IEEE Transactions on Mobile Computing*. Vol. 6, No 6. Apr. 2006.

[27] T. Karagiannis, J.Y. Le Boudec, M. Vojnovic. Power law and exponential decay of intercontact times between mobile devices. *IEEE Transactions on Mobile Computing*. Vol. 9, No. 10. Oct. 2010

[28] A.T. Campbell, S.B. Eisenman, N.D. Lane, E. Miluzzo, R. A. Peterson. People-centric urban sensing. *Proc. of WICON 2006*.

[29] L. Galluccio, G. Morabito and S. Palazzo. Spontaneous Group Management in Mobile Ad-Hoc Networks. *Wiley Wireless Networks*. Vol. 10, No. 4. Jun. 2004.

[30] K. Sampigethaya, L. Huang, M. Li, R. Poovendran, K. Matsuura and K. Sezaki. Caravan: Providing location privacy for Vanet. *Intl. Conference on Embedded Security in Cars*. Nov. 2005.

[31] C. Shannon. Prediction and entropy of printed English. *The Bell System Technical Journal*. Vol. 30. Jan. 1951.

[32] Universal Plug and Play. ISO/IEC 29341. Dec. 2008.

[33] Simple Service Discovery Protocol. *IETF Internet Draft*. Oct. 1999.

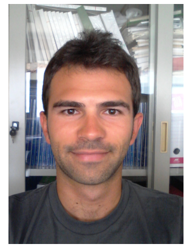
[34] H. Ko, S. Pack,and W. Lee. Timer-based Push Scheme for Online Social Networking Services in Wireless Networks. *IEEE Communications Letter*. Vol. 16, No. 12. December 2012.

[35] W. Wang and I. F. Akyildiz. A new signaling protocol for Intersystem Roaming in Next Generation Wireless Systems. *IEEE Journal on Selected Areas in Communciations* Vol. 19, No. 10. Oct. 2001.

[36] S.M. Mousavi, H.R. Rabiee, M. Moshref, A. Dabirmoghaddam. Mobisim: A framework for simulation of mobility models in mobile ad-hoc networks. *IEEE WiMOB 2007*. Oct. 2007.

[37] H. Zargariasl, A. Iera, L. Atzori, and G. Morabito. How often social objects meet each other? Analysis of the properties of a social network of IoT devices based on real data. *IEEE Globecom 2013*. December 2013. Atlanta (GA), USA.

[38] OPENCELLID, available at http://opencellid.org/



Salvatore D'Oro (S'12) received the B.S. degree in Computer Engineering and the M.S. degree in Telecommunications Engineering degree both at the University of Catania. In 2013, he spent a period as a Visiting Researcher at Centre National de la Recherche Scientifique (CNRS), Universit Paris-Sud 11, Paris, France. He is currently a PhD Student at the University of Catania and his main interests are next generation communication networks, security and game theory. In 2013 served on the Technical Program Committee (TPC) of the 20th European Wireless Conference (EW2014).

Laura Galluccio Laura Galluccio (M02) received the Laurea Degree in electrical engineering in 2001 and the Ph.D. degree in electrical, computer, and telecommunications engineering in 2005 from the University of Catania, Italy. Since 2002 she was with the Italian National Consortium of Telecommunications (CNIT), working as a Research Fellow in the FIRB VICOM and NoE SATNEX projects. Since 2010, she has been an Assistant Professor with the University of Catania. In 2005 she was Visiting Scholar with the COMET Group, Columbia University, New York. Her research interests include unconventional communication networks, software defined networks, and network performance analysis. She serves in the editorial boards of Elsevier Ad Hoc Networks and Wiley Wireless Communications and Mobile Computing journals.

Giacomo Morabito received the laurea degree and the PhD in Electrical, Computer and Telecommunications Engineering from the Istituto di Informatica e Telecomunicazioni, University of Catania in 1996 and 2000, respectively. From November 1999 to April 2001, he was with the Broadband and Wireless Networking Laboratory of the Georgia Institute of Technology as a Research Engineer. Since April 2001 he is with the Dipartimento di Ingegneria Informatica e delle Telecomunicazioni of the University of Catania where he is currently Associate Professor. His research interests focus on analysis and solutions for wireless networks and Internet of Things.

Sergio Palazzo (M92−SM99) received the degree in electrical engineering from the University of Catania, Catania, Italy, in 1977. Since 1987, he has been with the University of Catania, where is now a Professor of telecommunications networks. His current research interests include mobile systems, wireless and satellite IP networks, and protocols for the next generation of the Internet. He has been the General Chair of some ACM conferences, including MobiHoc 2006 and MobiOpp 2010, and currently is a member of the MobiHoc Steering Committee. He has also been the TPC Co-Chair of some other conferences, including IFIP Networking 2011, IWCMC 2013, and EuropeanWireless 2014. He currently serves on the Editorial Board of Ad Hoc Networks. In the recent past, he also was an Editor of the IEEE Wireless Communications Magazine, IEEE/ACM Transactions on Netrowking, IEEE Transactions on Mobile Computing, Computer Networks, and Wireless Communications and Mobile Computing.