On using P2P Technology to Enable Opportunistic Management in DTNs through Statistical Estimation

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***Abstract*—Disruption-Tolerant Networks (DTNs) are characterized by long delays and constant disconnections among nodes. These networks have management needs analogous to those of traditional computer networks, but, their intrinsic characteristics (*e.g.*, intermittent connections) hinder the execution of network management tasks. The employment of P2P technology is an alternative for managing DTNs since this technology promotes the autonomy of management entities (*i.e.*, management peers). This autonomy enables the use of local logic and data in order to perform opportunistic management tasks. We propose a solution to estimate the future contacts of nodes through distributed statistical analysis of past contacts. Besides that, nodes can share information about their contacts to improve contact estimation using a P2P management overlay. The proposed solution was implemented using an open source P2P-Based Network Management (P2PBNM) system, ManP2P-ng. Furthermore, the solution was evaluated through experiments performed using publicly available DTN traces. The results show that the proposed solution can improve the execution of management tasks in DTNs.**

I. Introduction

Network infrastructures have evolved considerably in last years, specially concerning their size, complexity, and heterogeneity. Besides that, the diversity of environments in which these infrastructures interconnect has also increased significantly. For example, now it is possible to operate in environments where the premises usually found in conventional networks, such as permanent connectivity among nodes and a low delay to exchange messages, are absent. However, the absence of these premises is not considered in the current network management solutions. Occasionally-connected and high-delay networks can be embraced by the Disruption-Tolerant Network (DTN) concept [2].

Current network management mechanisms (*e.g.*, SNMP[1] and NETCONF[2]) have been conceived for operation over less constrained networks, such as TCP/IP based ones, thus they are not directly deployable in DTNs. The execution of management tasks in DTNs could have better results if the pattern of the contacts of nodes are known. For example, management entities could save computing and networking resources by holding back monitoring requests until involved nodes are more likely to successfully contact one another. However, current network management mechanisms do not consider information about the frequency of contacts among nodes. Management tasks in DTNs can have better results if nodes have knowledge about the probability of contacts among nodes and, thus, perform these tasks opportunistically.

One natural option to realize opportunistic management is through the employment of Distributed Network Management (DNM) approaches, which in turn have led to improvements over the traditional centralized approaches. One particular DNM technology, also known as P2P-Based Network Management (P2PBNM) [3], which proposes the use of Peer-to-Peer techniques in network management, has several interesting characteristics for disruption-tolerant management, such as the use of local data and autonomy of management entities [6].

In the present paper we propose the utilization of local data and logic in a P2PBNM extension to estimate the best moment to execute distributed management tasks among nodes of a DTN. Nodes produce estimates using history information from contacts with other nodes. In this context, the main contribution of our work is to provide mechanisms to enhance the performance of the execution of distributed DTN management tasks. Besides that, we present the adaptation of an existing P2P monitoring mechanism to use our P2PBNM extension. Thus, we aim to show that is feasible to reuse network management mechanisms without important modifications through the employment of the proposed solution

The solution proposed in the present paper was implemented using *ManP2P-ng*, an open source P2PBNM system, as development platform. The implementation was developed to exploit the intrinsic flexibility of the employment of P2PBNM. Thus, our solution can be used by different management components of ManP2P-ng and to execute different management tasks. In order to evaluate the proposed solution, experiments and simulation analysis were performed using a set of traces produced during the operation of Vehicular Ad Hoc Network (VANET) [9]. These traces are publicly available by the *DieselNet* project[3].

The remainder of the paper is organized as follows. In

[1]SNMP - Simple Network Management Protocol
[2]NETCONF - Network Configuration Protocol
[3]DieselNet - http://prisms.cs.umass.edu/dome/umassdieselnet

Section II, we review key concepts related to DTN management. The employment of P2P technology to manage DTNs is shown in Section III. The proposed solution to estimate contacts among nodes is depicted in the Section IV. In Section V we present results of simulation experiments performed in order to evaluate our proposed solution. These experiments are validated using an proof of concept implementation which is shown in Section VI. Finally, concluding remarks and future work are presented in Section VII.

II. Disruption-Tolerant Network Management

The DTN Research Group (DTNRG), in the context of Internet Research Task Force (IRTF), has produced several documents related to DTN concepts and their implementation. The proposed architecture [2] is an end-to-end message-oriented overlay which employs persistent storage as delay and disruption tolerance mechanism. This overlay is called Bundle Layer and operates between the transport and application layers. However, network management mechanisms operating over DTNs are not part of an Internet standard yet.

The execution of management tasks in DTNs needs to address the main restriction from these networks: effectively establishing and maintaining control loops through the network infrastructure [1]. Control loops can be understood as cycles that begin with the access and gathering of management data, followed by its analysis and, possibly, the execution of network management commands. For sake of simplicity, we will focus only in a few proposed solutions to DTN management. It is also important to mention that we explicitly exclude probabilistic routing proposals, such as PRoPHETv2 [4] since they have a different focus, forwarding messages considering delivery predictability.

Peoples *et al.* [8] propose a extension for DTN management called Context-Aware Broker (CAB). CAB incorporates network environment information and application requirements to configure the data transmission automatically. For instance, the data transmission rate of VoIP applications can be automatically managed by CAB in order to save network resources. Besides that, CAB can provide the network requirements demanded by these VoIP applications. However, CAB is defined considering just a particular DTN, the InterPlanetary Internet (IPN).

Isento *et al.* [5] propose Moni4VDTN, a monitoring system for vehicular delay-tolerant networks. The authors propose an application-layer approach, where a dedicated server is deployed to collect load-related information from DTN nodes using SNMP. Despite the fact that authors claim that the system is SNMP-based, it is difficult to understand how the interaction between nodes and the server take place, therefore the proposed solution can be feasible only to the scenario presented on the paper itself.

III. The Employment of P2P Technology to Manage Disruption-Tolerant Networks

The employment of P2P technology in network management (also known as P2P-Based Network Management - P2PBNM) usually presents a high decentralization degree regarding the execution of management tasks. Besides that, nodes, *i.e.*, management peers, can share resources and exchange information. The decentralization features of P2PBNM system make them particularly adequate to manage DTNs since the use of a P2P management overlay avoids the need for a centralized management entity [6]. In this context, P2PBNM systems can provide a better connectivity considering network environments where disruptions are commonplace. Furthermore, the use of local information (data and logic) in these systems can improve the execution of management tasks in DTN infrastructures.

Traditional management interactions (*e.g.*, request-response) can be used over P2PBNM systems. These interactions can be effectively deployed using concepts from P2PBNM, such as management components and services. For example, P2P monitoring mechanisms are described in the network management literature [3]. However, these mechanisms break in the presence of intermittent connectivity because they sustain control loops among managed devices over supposedly stable connections. In this context, opportunistic contacts can hinder the execution of monitoring tasks since there is no guarantees on the frequency and length of contacts with the managed devices. Local information could be used to adapt P2P monitoring mechanisms when connectivity premises do not hold.

In summary, the employment of P2P technology can improve the management of DTNs, but there are still issues to be addressed regarding the connectivity of nodes for the execution of management tasks. In the next section, we tackle opportunistic management in DTNs using P2PBNM features to support the statistical estimation of contacts among nodes.

IV. Statistical estimation of contacts for opportunistic management

Network management solutions need to exchange messages so management entities and management elements may accomplish management tasks. However, opportunities to exchange messages in a DTN may be sporadic and delay-varying, thus, the execution of management tasks may be impaired. These opportunities can be defined as *contacts*. The DTNRG classifies contacts into five categories: persistent contacts, on-demand contacts, programmed contacts, opportunistic contacts, and predictable contacts [2]. Opportunistic contacts are particularly challenging regarding management tasks due to the lack of guarantees on the frequency and length of contacts.

Some basic properties of the underlying network infrastructure are assumed to hold even in the presence of opportunistic contacts. First, there is some amount of repeatability between contacts. In other words, it is assumed that contacts are not completely random events. Second, a monitoring mechanism is available on the nodes, thus it is possible to collect locally data regarding the contacts, such as involved nodes and the timing information.

The present work proposes the employment of P2P technology to enhance the execution of management tasks in DTN scenarios with opportunistic contacts. The P2P solution uses historical data about contacts among nodes to produce statistical estimates of future contacts. Based on these estimates, management peers can schedule their management tasks considering the moments when contacts are more likely to occur. Historical data about contacts can be locally collect or received by other peer nodes. P2P technology is used twofold by the management infrastructure: i) to apply local logic to collect data and perform statistical estimation; and ii) to enable the sharing of data among peer nodes through the provisioning of a P2P management overlay. We define 2 strategies to perform the statistical estimation, considering the different management data sources: *local strategy* and *local and remote strategy*. The remaining of this section describes both strategies and their concepts.

A. Local Strategy

The utilization of historical data about contacts is our approach to develop a method for establishing estimates of next contacts. In order to establish that, nodes employ local logic to compute statistical measures considering only local historical data. These measures are integrated to define the approximate moment of their next contact with managed elements. In this context, management entities may use the provided estimates in order to execute management tasks in a timely manner.

The local strategy is based on two procedures. First, it is necessary to keep track of contacts in order to store the local contact history (described in algorithm 1). After that, statistical metrics are computed using this history to provide contact estimates (described in algorithm 2). Then, management entities can use these estimates to perform opportunistic management tasks.

Algorithm 1 shows the details of storing contact history. For each remote node (*i.e.*, a node that the local node has contacted), the algorithm maintains 2 lists: one for date and time of the contacts and other for the time interval of these contacts. Besides that, the algorithm also includes a configuration parameter ($intervalMaximum$) which is a threshold controlling whether or not an interval must be gathered. This threshold arises as an intrinsic property of some DTN environments and its utilization can improve the estimation precision. The data gathered is used to compute the estimates of the next contacts with remote nodes. This estimate is given as a symmetrical interval, in terms of *minimum* and *maximum* boundaries for contact estimate. Different statistical measures can be used to compute these boundaries. For example, either measures of central tendency (*e.g.*, mean and median) or measures of dispersion (*e.g.*, variance and standard deviation) can be composed to define the maximum and the minimum value for estimates. Besides that, statistical models related to specific distributions or techniques such as one-way ANalysis Of VAriance (ANOVA) can be also used to compute the estimates.

Algorithm 2 shows the procedure to obtain the statistical estimate of the next contact. For example, if the procedure to calculate the mean of intervals ($calcMean$) returns that the mean is equal to 10 minutes and the procedure to calculate the standard deviation of intervals ($calcStdDev$) is equal to 3 minutes, therefore, the contact estimate is defined as 10 $\pm$ 3 minutes. In this case, the algorithm returns $lowerContEstimate$ as 7 minutes and $upperContEstimate$ as 13 minutes.

Algorithm 1 storeContactData($intervalMaximum$)

$interval \leftarrow dateTime - dateTimeLastContact$
if $interval > intervalMaximum$ **then**
  $contactsDateTime[nodeRemote] \leftarrow dateTime$
else
  $contactsDateTime[nodeRemote] \leftarrow dateTime$
  $contactsIntervals[nodeRemoto] \leftarrow interval$
end if

Algorithm 2 performContactEstimation($nodeRemote$)

$mean \leftarrow calcMean(contactsIntervals[nodeRemote])$
$stdDev \leftarrow calcStdDev(contactsIntervals[nodeRemote])$
$upperContEstimate \leftarrow mean + stdDev$
$lowerContEstimate \leftarrow mean - stdDev$
return $lowerContEstimate, upperContEstimate$

B. Local and Remote Strategy

The local and remote strategy builds up on the local strategy. Now, contact estimation is performed using information about past contacts, both locally collected and obtained from other nodes. Now, in each interaction, there are two distinguished phases: peer topology phase and contact estimation phase. The peer topology phase encompasses the selection of peer nodes. In its turn, the contact estimation phase provides the estimates of the next contacts with remote nodes, now considering also contact information received from peer nodes results.

The contact estimation phase resembles the previous described strategy (local strategy). Regarding the local and remote strategy, this estimation is also composed using information from correlated peers. However, it is necessary to assure that the received results have local relevancy. For example, if the contact pattern of two nodes, 'a' and 'b', to reach a third node, 'c', are completely disjoint, the use of contact information exchanged by the node a and node b concerning node c could lead to undesirable results (*i.e.*, decrease the precision of contact estimates). In order to avoid that, we use the concept of correlated peers [7]. In the context of present work, two nodes are considered as correlated peers if their contact patterns regarding another node are correlated.

The peer topology phase is responsible for the P2P management overlay provisioning. The peer topology phase proceeds as follows. To bootstrap overlay provisioning, each node uses their known endpoints neighbors as the initial seed to get candidate peers, *i.e.*, nodes that may be evaluated for correlation purposes. Then, nodes send information about their contacts for their candidate peers. Each node compares this information with their own contact history in order to evaluate the candidate peers and choose the top ones (*i.e.*, the ones with better correlation) to turn into correlated peers. The correlation procedure initially defined by the authors is a comparison using Student's t-test [7].

The contact estimation phase is taken place after the peer topology phase. The contribution of remote contact information improves contact estimation since only candidates peers with higher correlation scores are chosen to exchange information with. Besides that, it is possible to define upper and lower bound constraints for number of correlated peers of a peer in a given time which can decrease the resources needed to handle remote information and to assure that peers have at least a minimum correlation score.

Several parameters can be defined to shape the way the remote strategy works. As a superset of local strategy, some of these parameters have also impact when only the local history of past contact is used. First, the possible number of correlated peers can be configured, in order to decrease the amount of generated traffic and the resources needed to process contact information exchanged. Second, the amount of contact information that is stored by the local node can be also specified, which delimit the required storage. Finally, it is also possible to "tune" the contribution from correlated peers, in terms of the weight given to received contact information.

V. Simulation Experiments

Simulation experiments were used to evaluate the feasibility of the basic concepts of our proposed solution and to capture initial configuration parameters. Therefore, we simulate only the local strategy (described in the Section IV). We called our proposed solution *Opportunistic Management Contact Estimator* (OMCE). We developed a set of scripts that use OMCE to analyze the contacts history from trace files.

The set of traces [10] used to perform the analysis of our proposal are records of a real DTN, a VANET called University of Massachusetts (UMass) DieselNet. These traces were collected in the first half of 2006, between January and May. Weekends, holidays and recesses are not included in these traces. The UMass DieselNet consists of about 40 buses running around the UMass Amberst campus. Each bus has a Global Positioning System (GPS), an Access Point (AP) IEEE 802.11b, a second IEEE 802.11b interface and a computer with the Linux operating system installed.

Contacts among buses which occurred in close time intervals were grouped in into a single contact. This is done to avoid the "Parking lot problem", a group of buses that came together and repeatedly exchange information [4]. After some experiments, we chose 30 minutes as the limit to group contacts. In addition, traces were stored in a PostgreSQL database in order to make their processing easier. Besides that, the contacts that took an excessive time to occur in relation to their previous contacts are not taken in consideration either. In the experiments, the accuracy of OMCE results increased when using 25 hours as an upper bound.

The graph shown in Figure 1 illustrates the contacts among the peers found in the traces. Each bus is identified by a vertex and the contacts among the buses are represented by edges. This image shows all contacts found in the trace files.

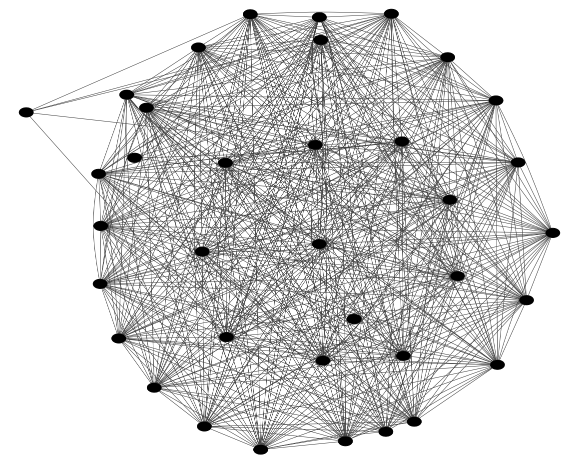

Fig. 1. Graphs representing connections among the buses.

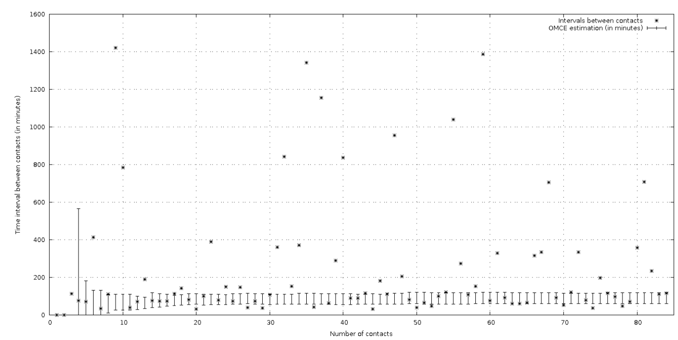

Fig. 2. Estimation using Confidence Interval.

It is important to note that even with the occurrence of several contacts between two buses, there is only one edge that connects both. This approach was used to improve the visualization of the graph. In this figure it is possible to notice a pattern of connectivity among the buses, *i.e.*, most buses have at least one contact with almost all other buses.

We performed experiments considering 2 approaches to estimate when next contacts would occur. First, we used a confidence interval of 95% as the time range estimate considering the previous contacts as the contacts sample. Figure 2 shows the results for estimation using confidence interval. Besides that, we performed experiments considering the time range as a composition of mean and standard deviation from past contacts. Figure 3 shows results for this composition. Both graphics present contacts between 2 particularly nodes, buses with identifiers 3046 and 3041.

The results showed that from 112 contacts, 36 contacts occurred within the time interval provided by OMCE considering confidence intervals. Using the composition of mean and standard deviation, 44 contacts of the 112 were hits. Despite the difference (8 contacts), it is safe to say that both estimations have similar performance (considering the present setting). In this context, OMCE can help increase the performance of management tasks through an optimization on the generation of management requests and responses. However,

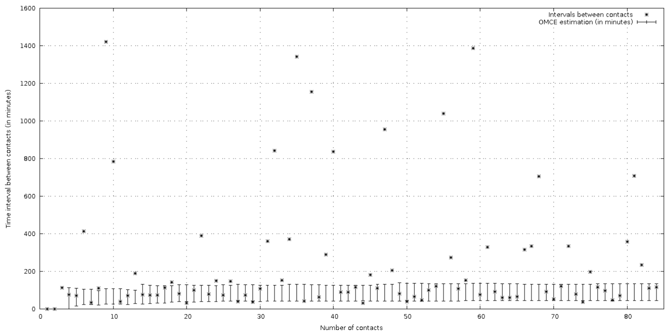

Fig. 3. Estimation using a composition of mean and standard deviation.

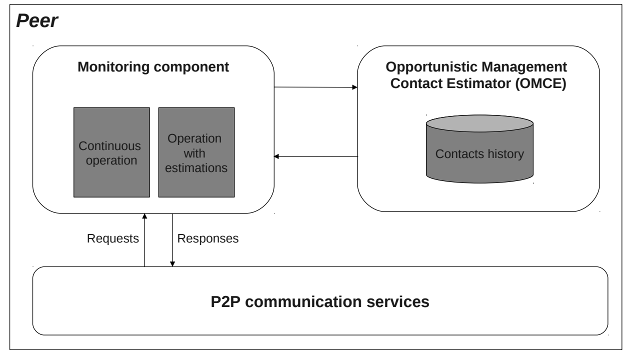

Fig. 4. OMCE operation.

it is important to note that the effectiveness of OMCE can increase or decrease according to network characteristics.

VI. Validating the Simulation Experiments

We presented in Section V results obtained through simulation experiments. In order to verify the accuracy of our simulations, we performed experiments using a proof of concept implementation on *ManP2P-ng*[4], an open source P2PBNM system. This system uses the event-driven networking engine *Twisted*[5]. *ManP2P-ng* provides an API to make the development of new management applications easier. The implementation which uses this API illustrates the technical feasibility of integrating OMCE on a P2PBNM system. The solution was written using python which is the programming language supported in ManP2P-ng and Twisted. We used the same set of DTN traces used for the simulation experiments.

The relation between OMCE and other software components inside management peers is presented in Figure 4. OMCE uses local logic and data to perform the local and remote strategies in order to provide statistical estimation of future contacts. Thus, each management peer handles its own estimates without the need to contact centralized management parties. Besides that, it is possible to use the P2P management overlay to exchange information about past contacts among nodes in order to improve the contact estimates.

The implementation is composed of OMCE and an adaptation of the monitoring component from *ManP2P-ng* (as shown in Figure 4). OMCE encapsulates the choice of the statistical metrics used to produce the contact estimate. Initially, 2 metrics were coded to estimate next contacts: one composed of a measure of central tendency (mean) and a measure of spread (standard deviation) and one considering the confidence interval produce by ANOVA. The adapted monitoring component has 2 modes of operation, which allow a proper evaluation of OMCE features. The first mode of operation, requests are sent to the managed device in a continuous way. The second mode of operation considers the estimates provided by OMCE in order to send requests within the time range when the contact is more likely to happen. Besides the monitoring component, other management components from ManP2P-ng can also use OMCE estimates.

The information provided by OMCE can be used for different management tasks. In the present section OMCE is used to improve the monitoring of network device in a VANET. The number of requests between a management entity that uses OMCE is compared with the amount of requests generated by a management entity that does not use OMCE. In this scenario, the management entity and the managed device undergo various disconnects, and the communication between peers can only be performed at certain times. For other times, any attempt of communication will not reach the destination resulting in an unnecessary consumption of computer resources, which is undesirable in DTNs.

Peers contained in the traces that have the largest number of disconnections between them were selected to represent the management entity and the managed device. The rationale for this choice is due to the assumption that the more contacts, the more precise the proposed solution should be. For the experiments, the ManP2P-ng was run in the management entities and the managed device.

The evaluation of the local strategy was performed for 2 statistical metrics. First, the management entities performed several requests to a managed device without the use of estimations provided by OMCE. After that, the management entity carried out its requests to a managed device now considering the estimations provided by OMCE. Now, the management entity starts sending the requests only within the time range suggested by OMCE (*i.e.*, where the contact would likely occur). The requests ceases only when a response is received by the management entity.

Figure 5 shows the results for the evaluation of local strategy. According to the results, the OMCE assisted ManP2P-ng to decrease approximately 30% of the sent requests.

The results from the local strategy show that OMCE needs a certain amount of information about past contacts in order to estimate future contacts accurately. The P2P sharing of contacts history can accelerate the achievement of the minimum data necessary to start the prediction of future contacts. The

[4]http://projects-redes.inf.ufrgs.br/gf/project/manp2png
[5]http://twistedmatrix.com/trac

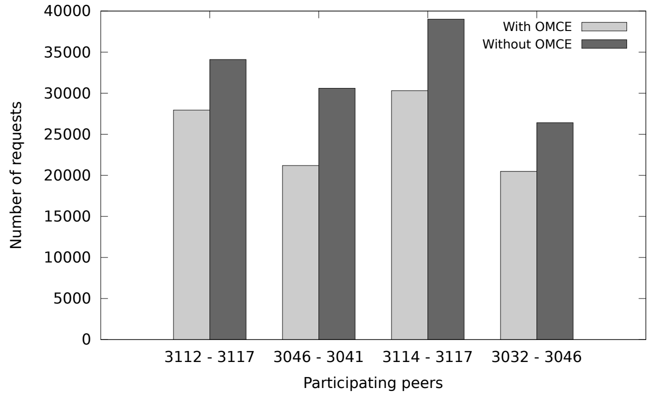

Fig. 5. Results of experiments using the local strategy.

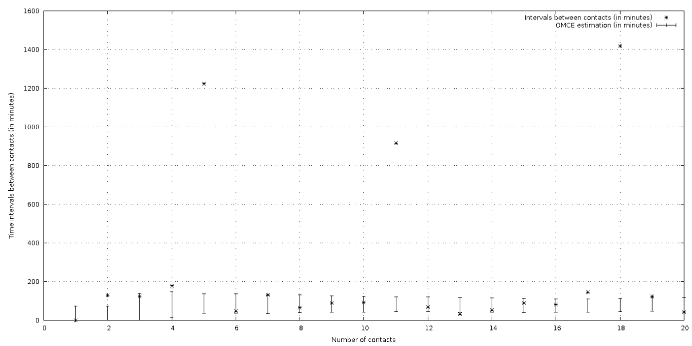

Fig. 6. Results of experiments.

concept of correlated peers (described in Subsection IV-B) can be used to define which nodes are suitable to become peers and to start to exchange information about past contacts.

Figure 6 presents the results of local and remote strategy. It is possible to verify that this strategy can quicken the accurate prediction of future contacts compared to the local strategy. This is important specially considering the initial results since there is a small amount of contacts in the contacts history which can be process to provide the estimate.

VII. Conclusions and Future Directions

The support of management demands in new network infrastructures is an important investigation topic regarding the network management area. One of these demands is the support to execute management tasks on environments with intermittent connectivity, such as Disruption-Tolerant Networks (DTNs). However, current network management solutions are not prepared to operate in DTN environments. Opportunistic management features can be used to enable the execution of management tasks in DTNs. These features can be provided through the employment of P2P technology. This technology allows that local information be used to avoid the dependency on centralized management parties and to enjoy opportunistic contacts among nodes to exchange management information within a DTN.

In the present paper we proposed *Opportunistic Management Contact Estimator* (OMCE), a solution to enhance the execution of P2P opportunistic management tasks on DTNs. The solution estimates the appropriate time to execute management tasks considering statistical measures of the history of past contacts. We presented 2 strategies to compute the estimates: a local strategy (using only the local contact history); and a remote strategy (using both local contact history and information received from management peers). The evaluation of OMCE was performed considering 2 approaches, simulation experiments (to understand the properties of the contact estimation) and a proof of concept implementation (to validate the simulation). The results shown that is possible to improve the performance of the execution of monitoring tasks using OMCE, considering both strategies.

Our work is intended to be an initial step towards the opportunistic management of DTNs. In spite of the good results obtained from the performed evaluation, new features can improve our proposed solution. It is possible to include different statistical approaches to process the contact history, such as new measures of central tendency and spread. In this context, an autonomic mechanism could be used to evaluate the efficiency of several statistical measures used to estimate the next contacts and choose adaptively which is performing better. It is also important to evaluate our proposed solution considering other VANET traces as well as DTNs with different characteristics.

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