A CONTEXT MODEL FOR AUTONOMIC MANAGEMENT OF AD-HOC NETWORKS

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Abstract: Management of next generation networks is challenging due to increased complexity imposed by their dynamic and heterogeneous characteristics. The deployment of mesh wireless networking topologies, the support of diverse networking functionalities and the existence of large number of heterogeneous devices make traditional approaches inappropriate. In such environments, the description of the basic networking entities and the interactions that are present, as well as the relationships among them, is crucial. Proper representation may facilitate the operation and management of the network, as well as the optimal adaptation to the current environmental conditions, and thus, optimise the performance of the network mechanisms. In this paper, a context model is proposed for ad-hoc networks aiming to present in detail the correlation among the network entities and interactions in dynamic environments. Specific functionalities that may be designed taking in account the description of the context model are described and indicative implementation scenarios are implemented and evaluated.

1 INTRODUCTION

Next generation networks are becoming more complex and dynamic through the interconnection of large number of heterogeneous devices, the deployment of mesh networking topologies and the support of diverse networking functionalities. Ad-hoc communication among independent nodes in a network, frequent topology changes due to inherent dynamic network characteristics, exchange of roles among the nodes in a network and merging or splitting of groups of nodes are expected to be dominant characteristics of future networking enviroments.

The Future Internet is envinsioned to become a service-aware networking environment where each node will be able to undertake the role of the service or content provider. Services may be composed or decomposed according to the availability of resources and applied policies while, in addition, provision of services have to be conducted in a unified way.

By taking into account this evolution, there is a necessity to design new paradigms to accomplish efficient management of next generation networks. The incorporation and combination of concepts like self-adaptation, self-configuration, self-awareness and self-healing to the current networking conditions as well as the support of decentralized management schemes is required. In this manner, high level goals in the network may be achieved in an autonomous manner without the need for predefined centralized infrastructure.

A promising method for the distributed and self-management of next generation networks, as well as the provision of advanced services in dynamic environments, is the establishment of logical overlays on top of existing physical networks. In an overlay network, knowledge may be shared among the network nodes and the network may be re-organized according to the nodes' content or the supported functionalities. The underlying network topology changes may be hidden and reliability in the provision of services may be assured.

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In addition to the establishment of overlay networks, knowledge representation and proper interpretation of the acquired context is crucial for the support of complex management tasks. Through appropriate context representation, each node in the network may be able to efficiently sense its environment through the establishment of interaction with neighbouring nodes and extract knowledge based on it (self-awareness). Moreover, concepts like the quality of collected context (QoC) (Buchholz, 2003) (Krause, 2005), the supported functionalities and roles of each node, the scope of the collected information (a.k.a. whether the information is useful for neighbouring nodes or for all the nodes in the network) and the node and network temporal characteristics (e.g. mobility ratio, location etc.) may be efficiently expressed and combined for information fusion purposes. Ad-hoc nodes may dynamically evaluate the acquired context according to predefined rules and exchange knowledge based on it, while knowledge of the existing policies and conditions in the network may facilitate the distributed decision making process. Through proper allocation of roles within the network, distributed reasoning may also be achieved in local, cluster and network level.

In this paper, focus is given on the description of a context model that describes the basic entities and interactions that are present in dynamic networking environments. The designed context model expresses and correlates the networking entities in an ad-hoc network, their environmental characteristics and the imposed policies on the network, aiming at facilitating the operation and management of the network, as well as optimising the performance of the network mechanisms. The presented approach extends our previous work on designing an architecture for autonomic services provision in dynamic networks through the establishment and maintenance of an overlay network (Gouvas, 2010). An overlay network may be used as distributed repository of context aware information that can be shared among the participant ad-hoc network nodes.

The paper is organized as follows; Section two briefly presents the current work in the field of context awareness support in dynamic heterogeneous networks. Section three describes the requirements that have to be fulfilled for the proper design of a context model for ad-hoc networks, details the proposed context model, as well as the basic functionalities that may be supported. Section four describes the emulation results based on the optimisation of specific network mechanisms and, finally, Section five concludes the paper with a short summary of our work and a discussion of open issues and future work.

2 RELATED WORK

Several approaches have been proposed for autonomic management of ad-hoc networks. These include techniques for distribution of functionalities and roles in a dynamic environment, design of context models for description of interactions within an ad-hoc network as well as methodologies for distributed processing and reasoning of context data.

The design and implementation of a system that exploits context-awareness and couples it with policy-based management in order to enable the self-management of mobile ad-hoc networks (MANETs) is presented in (Malatras, 2007). It is proposed that management of MANETs has to be done in a hierarchical but also distributed manner through a dynamically constructed set of manager nodes. Similarly, the vision of realizing the idea of a “self-organized data ecosystem” by defining proper models and tools to represent, analyze, self-organize, and self-aggregate contextual information, so as to form structured and meaningful collections of related knowledge items is described in (Bicocchi, 2010). It is stated that the evolution must be from models of context awareness in which the focus is to provide services with simple interfaces to access heterogeneous context providers, towards models of situation awareness in which a middle layer is in charge of organizing sparse pieces of information in order to provide services with a pre-digested and more comprehensive higher level knowledge.

A layered reference model that encapsulates suitable abstractions to tackle the complexity of context management in mobile ad-hoc networks is proposed in (Dudkowski, 2008). The proposed model comprises of three major layers, each of which addresses a specific part of the overall complexity of context management: core storage, update processing, and context services. Respectively, in (Christopoulou, 2010), focus is given on the exploitation of context in ubiquitous computing environments through its modelling using ontologies and on the reasoning process based on intelligent context and rules defined by the user.

Important effort is also dedicated on the description of techniques for distributed data and knowledge acquisition. Context data distribution is defined as the capability to gather and timely deliver relevant context data about the environment to all interested entities in an ad-hoc network (van Sinderen, 2006). A simple way to specify context data distribution requirements is proposed in (Corradi, 2010), along with an approach for quality-aware context data distribution in mobile and wireless wide-area environments. In (Macedo, 2009) a distributed entity and an information schema is described to store and disseminate information concerning the network, its services and the environment, orchestrating the collaboration among cross-layer protocols, autonomic management solutions and context-aware services. Moreover, in (Rizou, 2010) the problem of designing a distributed system for the detection of situations in highly dynamic environments is addressed. An architecture is introduced that enables the efficient distributed processing of context data in large-scale overlay networks.

2.1 Motivation & Contribution

Based on the already proposed approaches, it may be argued that through the support of context awareness in dynamic networking environments, self-adaptability can be achieved in the supported mechanisms and network nodes may fulfil network-level goals that derive from high-level policies. However, the description of a representative context model for interactions in ad-hoc networks that combines and presents the concepts of dynamicity, distribution of roles and resources, knowledge extraction through interaction of the ad-hoc network nodes and adaptation to the existing mechanisms in the network according to the imposed goals and policies, need to be further investigated. Furthermore, techniques that enable the distributed storage and dissemination of knowledge in the network are not analyzed in detail in the literature.

The motivation for the design of the context model that is proposed in this paper is the description of a reference model for the implementation of context management in MANETs that combines the above mentioned concepts. The proposed context model is generic enough in order to support diverse networking environments, functionalities and deployment scenarios. The description of the context model is based on an already proposed architecture for providing autonomous and decentralized services in dynamic environments through the establishment and maintenance of overlay networks, as it is described in (Gouvas, 2010). Overlay networks may be used as distributed repositories where context aware information may be shared among the participant ad-hoc network nodes and service development may be realized independently from the underlying physical network. Finally, mechanisms that may be applied in large scale networks (e.g. clustering mechanisms in wireless sensor networks (Zafeiropoulos, 2010)) are also considered.

3 CONTEXT MODEL FOR AD-HOC NETWORKS

3.1 Requirements

An efficient context model for ad-hoc networks should fulfil the following requirements (Malatras, 2007): a) be extensible in order to describe a rich set of interactions, concepts and functionalities, b) be interoperable with existing models, c) support accurate descriptions and d) require limited memory and processing power in order to be suitable for resource constrained devices.

Proper representation and description of the context information is important. Context information is considered as incorrect if it fails to reflect the true state of the world it models. It is also regarded as inconsistent, if contains contradictory information. Also, it is considered as incomplete if some aspects of context are unknown (Henricksen, 2002). Thus, in order to accurately describe the acquired context information, it is desirable to achieve high *Quality of Context (QoC)* (Buchholz, 2003) (Krause, 2005). Various parameters may be used to characterize the quality of (context) information from different perspectives, such as *freshness* (i.e. time passed since the creation of the content), *precision* in the estimation, *scope* (e.g. local, cluster or network level), *trust-worthiness*, *privacy*, *retrieval time* from the content requestor, *replication* degree, *volatility*, etc.

The context model should fulfil several requirements imposed from the dynamicity of ad-hoc networks. Different roles have to be supported for the network nodes (e.g. router, gateway, cluster head) since delegation of roles is a dynamic and evolving process and depends on the nodes capabilities and the overall network policies. Moreover, concepts like mobility (e.g. frequency of link breaks with neighbours), available energy and network topology formation (e.g. size and degree of the network) have to be expressed. The definition of a hierarchical structure that the ad-hoc network nodes may follow as well as the possible ways of interaction among the network nodes during the information flow procedure have also to be described. The scope for each type of data (e.g. local, cluster, global level) has to be defined and be interconnected with the type of the repository that will be used (e.g. distributed repository, centralized database).

Finally, the context model has to support description of policies and available services in the network. The definition of a policy has to be in a suitable format, able to be correlated with the represented context data. Policies definition has to be conducted according to the high level goals that are imposed by the network administrator and the events that are extracted from the context model and the services description.

3.2 Context Model Description

The proposed context model (Figure 1 – Figure 4) aims at describing the existing entities and interactions in an ad-hoc network as well as basic functionalities that these entities may support. The basic entities of the context model are the *Node* that is able to proceed to *Decisions*, to undertake *Actions* and to conduct proper *Reasoning* over the acquired context. The *Node* supports specific *Functionalities* (e.g routing, security, QoS protocols and mechanisms, etc) and, through a decision making process, is able to affect their *Configuration Parameters*. This is necessary in order to support self-optimisation and self-adaptation to the existing conditions in the network. Furthermore, according to the supported *Functionalities*, each *Node* may be associated with specific *Roles* (e.g. cluster head in case of application of clustering mechanisms) (Figure 1).

The *Node* contains *Monitoring/Sensory Interfaces* through which it senses specific *Context Parameters*. Each *Monitoring/Sensory Interface* is able to measure or sense networking parameters (e.g. size and density of the network), mobility parameters (e.g. percentage of dynamicity in the network), connectivity parameters (e.g. list of neighbours), environmental metrics (e.g. sensor measurements) and the node status (e.g. available energy). Each *Context Parameter* has specific *Parameter Attributes* that express attributes related with the QoC for this parameter. These attributes include freshness, scope (local or global), volatility, privacy, replication degree, confidence interval, sampling frequency and user-related community, etc. According to the scope of the acquired data, it may be stored either at the *Distributed Repository* or -centrally or locally- in specific *Nodes* (Figure 1).

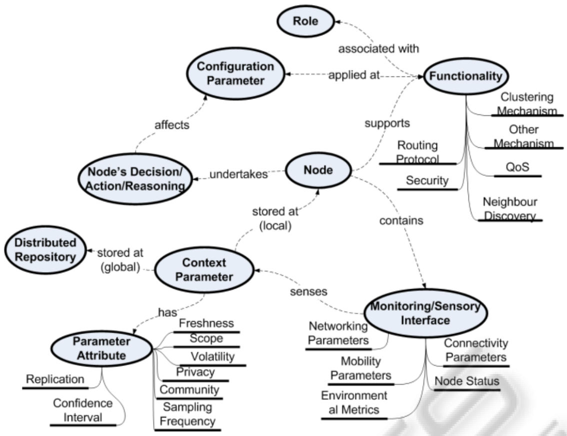

Figure 1: Supported functionalities and roles by each network node.

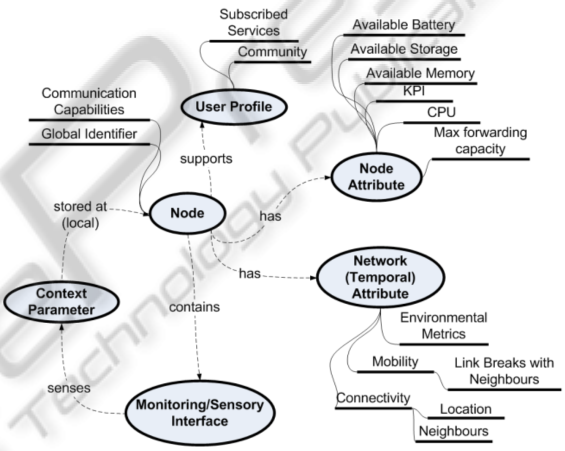

Figure 2: Node attributes and user profiles.

The *Node* has *Node Attributes* and *Network Attributes* that may be constant or temporal. *Node Attributes* include the available battery, storage and memory, the CPU, the maximum forwarding capacity and a Key Performance Indicator (KPI) that may be variable according to each application needs (e.g. mainly computed based on available energy on power-constrained nodes). *Network Attributes* include connectivity attributes such as the current location and the list of neighbours, mobility attributes such as the number of link breaks with neighbours in a specific time period, and environmental metrics. The *Node* has also a global identifier (e.g. IPv6 address), specific communication capabilities and supports specific *User Profiles* (Figure 2).

An important part of the model is the policy-based decision making process description. The description is based on the aim of fulfilment of the specified *Goals* in the network that may be related with the technical or business perspective. These *Goals* are described through *Policies* based on the selected policy description language (e.g. Common Information Model Simplified Policy Language CIM-SPL (DMTF CIM-SPL, 2010)). Each *Policy* has a specific applicability scope since it may regard a local or network wide decision and is comprised of *Rules*. The *Rules* are based on combination of *Conditions* and *Events* that are even described including specific *Context Parameters* or combine also *Knowledge* that is extracted based on the *Node's Reasoning* process. The advantage of this definition is that *Knowledge* that is produced during the network operation and evolution may be exploited and specific *Events* and *Context-aware Parameters* may be also used in the *Rules* definition process. The *Rules* have applicability and storage scope and may be stored either in the *Distributed Repository* or -centrally or locally- in specific *Nodes*. Depending on the network environment and the supported services characteristics, *Rules* may be preferable to be commonly accessible for all network nodes including those that join currently the network. In this case, their storage in a *Distributed Repository* is recommended. *Rules* that reason on decisions and actions based on global knowledge may be similar with *Rules* that are based on local knowledge. According to their applicability state, they will be applied in the appropriate region (Figure 3).

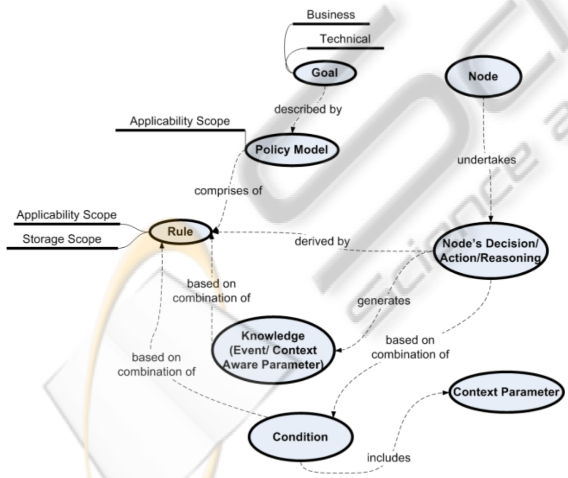

Figure 3: Network goals, policies and rules.

The imposed *Policies* are also associated with the supported *Services* in the network that have specific QoS characteristics and priorities. Each *Service* may initiate several *Flows* in the network that are established within end-to-end paths. The *Flows* are characterized based on the source node, the destination node, their priority and QoS characteristics, the signalling information and maybe from a flow record (e.g. as defined in IPFIX). The context model is designed in order to be compatible with existing models for description of policies, services, monitoring and QoS characteristics (DMTF CIM, 2010) (TMF, 2005) (Schmohl, 2008) (Ferreiro, 2009).

Another important aspect in the design of the context model is the specification of the way that information may be *disseminated* in the ad-hoc network. This information regards the available data in the network as well as the defined policies and rules. As stated earlier, information may be stored either in specific *Nodes* (locally or centrally) or in the *Distributed Repository*. Information exchange may be accomplished via interrupt based or polling based techniques. In order to succeed distributed storage and dissemination of information, the approach proposed in (Gouvas, 2010) may be followed or alternative methods and techniques may be designed and developed.

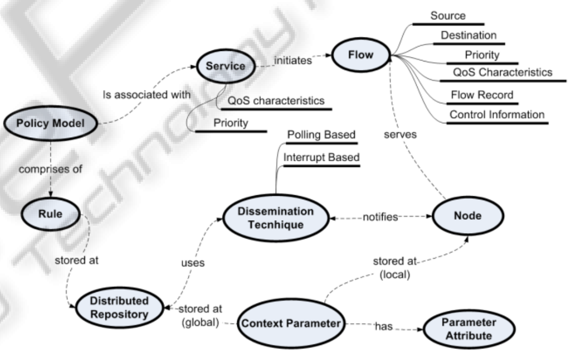

Figure 4: Dissemination of information within the network.

3.3 Supported Functionalities

Several functionalities may be designed according to the specified context model for improving the operation and management of the ad-hoc network. Indicatively, roles may be assigned in the network nodes according to their capabilities based on the definition of a Key Performance Indicator (KPI) function. Similarly, according to the dynamicity that is present in the network several actions may be taken, such as a) increase in the data replication degree in the overlay network in order to ensure that valuable data will not be lost and b) re-initiation of mechanisms for autonomic estimation of network based parameters for acquiring an up-to-date view. The percentage of dynamicity in the network may be given by the ratio *mobility_ratio=link_breaks/neighbours* (Buchholz, 2003) for a specific time period. Adaptations may also be supported in the routing protocols applied in the ad-hoc network. According to the levels of dynamicity in the network, the use of proactive or reactive routing protocols may be preferable (e.g. in case of a highly dynamic environment, reactive routing protocols have to be selected).

Furthermore, modifications and self-optimisation actions may be supported in mechanisms that are mostly applied in large scale networks (e.g. large wireless sensor networks). An important functionality in such networks is usually the aggregation of data by special nodes and the adaptation in the frequency of collecting data according to the network conditions. Responsible nodes for aggregation are defined taking in account also the context scope. Threshold criteria may be defined for specific actions according to the collected data (e.g. when the available energy in the cluster is low, reduce the frequency of data sampling). Similarly, in case of application of clustering mechanisms, if the cluster head (CH) senses reduction in its available energy, it may quit from this role and return to normal operation.

The context model may be used in various network monitoring and management scenarios, since interoperability with existing context models related with traffic monitoring and QoS provision is supported. Through interaction with the imposed policies and the supported rules in the network, self-optimisation and self-configuration decisions may be taken. An indicative scenario for autonomic traffic monitoring and management, based on the designed context model is described in section 4.

The context model also supports information regarding user profiling and preferences. This information is usually proactive (known beforehand). According to this information, the user may be correlated with existing content in the network (e.g. content characterized for this community). Finally, security and privacy issues declared by the user may impose specific adaptations in the functionality of the supported mechanisms.

4 EXPERIMENTAL RESULTS & EVALUATION

Two indicative scenarios are examined in this section, in which the identified interactions are described according to the proposed context model. Based on tests results, we claim that significant improvements may be achieved by dynamically adapting a routing protocol or an application-level mechanism in an ad-hoc network. Focus, though, is given on the applicability of the context model in diverse networking environments rather than on optimising the selected protocol or mechanism.

The experiments are conducted in an emulation environment where a wide set of topologies are formed by initiating multiple mobile nodes. The prototype implementation is developed in Java and supports the bootstrapping of a (multi-hop) ad-hoc network and the communication among the participating nodes. A topology editor is also implemented in order to examine the various mechanisms in specific topologies.

Table 1: Description of scenario 1 according to the context model.

```
<goal name="reduce_Signaling_Overhead">
   <ruleset name="reduce_Flooding">
      <rule name="adapt_HTL">
    <condition-set operator="and">
     <operant name="Network_size"
        scope=”global” value="N"/>
     <operant name="Network_density"
          scope=”global” value="d"/>
    </condition-set>
    <action-set>
     <action name="RoutingRegulation">
       <config layer="Routing"
           param_name="Route_Req_HTL"
           param_value="f(N,d)" />
       <config layer="Routing"
           param_name="Route_Error_HTL"
           param_value="f(N,d)" />
     </action>
    </action-set>
      </rule>
    </ruleset>
</goal>
```

In the first scenario, a network with diverse size and density bootstraps. It is assumed that the network nodes are able to estimate the size and the density of the network through the application of gossiping techniques for estimation of network based parameters (Gouvas-MONET, 2010). A Constant Bit Rate (CBR) flow may be established between any two nodes in the network and the routing performance is estimated for the following cases: i) the Hops-To-Live (HTL) parameter is dynamically adapted according to the current size and density of the network, and ii) the Hops-To-Live (HTL) parameter is set to infinite.

In Table 1, the description of the *Goals*, the *Rules* and the *Actions* for the realization of the scenario is shown based on our proposed context model. The *Goal* for the network is to reduce the unnecessary flooding of messages. A *Rule* is defined for specific *Actions* according to the values of the size (*N*) and density (*d*) global parameters. The HTL value for routing request (*Route_Req_HTL*) and routing error messages (*Route_Error_HTL*) is defined according to a function *f(N,d)*. Thus, during the network bootstrap or after a network topology change, the *Rule* is executed and the HTL parameter value is adapted accordingly. The total number of messages exchanged in mesh and Barabasi-Albert topologies is shown in Figure 5, where the size and density of the network vary from 10 to 40 nodes and from 2 to 4, accordingly.

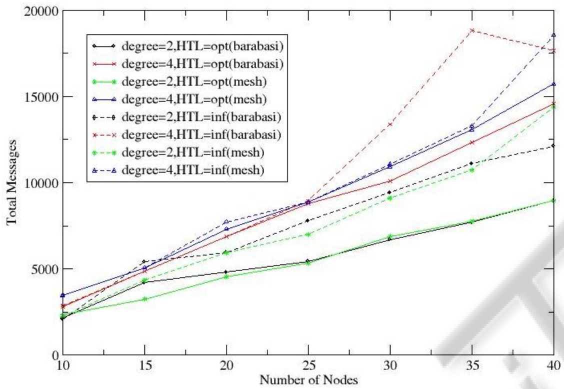

Figure 5: Total number of messages exchanged in mesh and Albert-Barabasi topologies.

In the second scenario, an Albert-Barabasi network topology is established for various network size and density. At specific time periods, traffic flows are initiated among network nodes and a specified sink node. There are two types of flows; CBR flows with rate of 10Mbps, and monitoring flows with rate of 1Mbps. For each CBR traffic flow, a monitoring flow is initiated between the same source and the destination node for management purposes. The monitoring flow is able to collect measurements and statistics for specific traffic performance metrics, e.g. delay, jitter, congestion, etc. According to the collected measurements, distributed monitoring and management may be performed in the ad-hoc network, as it is described in (Liakopoulos, 2010).

The *Goal* in the network is to achieve high monitoring accuracy without posing negative impact in the generated traffic. According to the existing policy, the monitoring accuracy is desired to be as high as possible provided that there is no congestion. In case of congestion, the monitoring accuracy should be reduced to a minimum level in order to free scarce resources. Therefore, in cases that the generated traffic is increased significantly and congestion may appear in the network, traffic generated by monitoring flows is eliminated (throttling). The following *Rule* is imposed for this purpose: when a node serves traffic more than 30 Mbps, it drops the signalling (monitoring) packets. If the served traffic goes again under 30 Mbps in the future, signalling packets are forwarded. In Table 2, the description of the *Goals*, the *Rules* and the *Actions* for the realization of the scenario is shown based on the designed context model.

Table 2: Description of scenario 2 according to the context model.

```
<goal name="reduce_Signaling">
  <ruleset
name="throttle_Monitoring_Pkts">
   <rule name="regulate_Pkts">
    <condition-set operator="and">
     <operant name="link_Utilisation"
       scope=”local” value="N"/>
    </condition-set>
    <actionset>
     <action name="regulate_Pkts">
      <config layer="Application"
        param_name="Monitor_Pkts_Served"
        scope="local"
        param_value="f(N)" />
     </action>
    </actionset>
   </rule>
  </ruleset>
</goal>
```

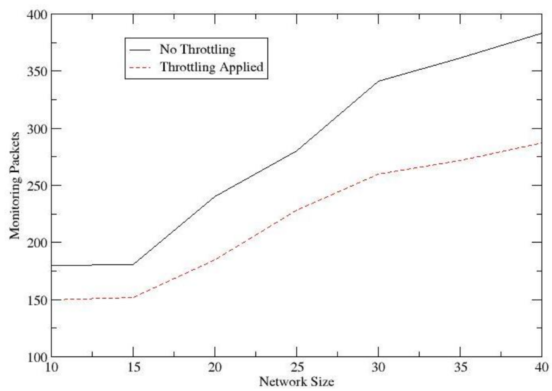

Figure 6: Monitoring flow packets served.

The total number of messages for the monitoring flows and the CBR traffic flows in case where the traffic monitoring *Rule* is applied or not is depicted in Figure 6 and Figure 7, accordingly. It is shown that, in case of application of the defined *Rule*, the number of served monitoring packets in the network is reduced in case of high utilisation in comparison with the case where no rule is imposed. Similarly, the total number of messages served in the case where the *Rule* is not applied is larger. However, in case of congestion, the QoS provision could be deteriorated in this case compared with the case where the *Rule* is applied.

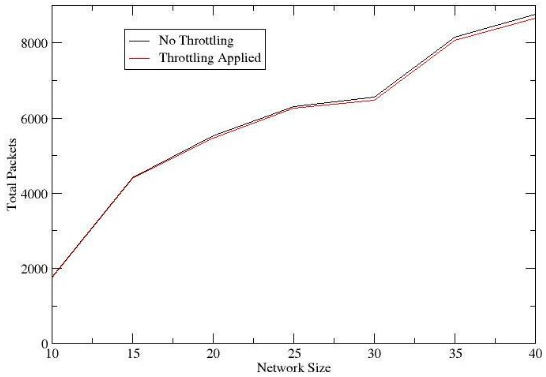

Figure 7: CBR flow packets served.

5 CONCLUSIONS

In this paper, a context model for ad-hoc networks is proposed. The model takes in account the need for proper representation of the network entities and their interactions that are present in various dynamic environments. It also aims to improve the context awareness level in the network and, thus, facilitate the realisation of autonomic management mechanisms. In addition, the dynamic adaptation of protocols to the current network conditions may also enable the realisation of self-optimised functions among independent nodes.

In our future work, we plan to design more complex scenarios based on the proposed context model and present the optimisation that may be succeeded by allowing dynamic adaptation of network protocols and mechanisms. Furthermore, an important research issue is related with the design and development of methods for providing distributed reasoning functionalities in a dynamic environment. Novel techniques for rules and policies storage and distribution in the network, as well as intelligent ways for autonomic and distributed decision making mechanisms have to be further examined.

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