An Approach to Context Representation, Discovery and Sharing in Mobile Ad-Hoc and Sensor Networks

Qi Liu[1], Nigel Linge[2] and Huai-Guang Wu[3*]

[1]*Jiangsu Engineering Center of Network Monitoring, Nanjing University of Information Science & Technology, Nanjing, 210044, China*
[2]*Computer Networking and Telecommunications Research Centre, University of Salford, Salford, Greater Manchester, M5 4WT, UK*
[3]*School of Computer and Communication engineering, Zhengzhou University of Light Industry, Zhengzhou 450000, China*
qi.liu@nuist.edu.cn, n.linge @salford.ac.uk, hgawu@126.com

Abstract

The representation, discovery and exchange of context information in a mobile ad-hoc environment is challenging due to the dynamic nature of node movement and interaction. In this paper a new method to exchange context in a Mobile Ad Hoc and Sensor Network (MSN), where the format of context parameters are organized and efficient communication is maintained. A context representative repository, called Context information Base (CiB) and a communication protocol called Context information Communication protocol (CiComm) are presented to implement contextual features. NS-2 has been used to simulate our work, which depicted high context discovery success and low service discovery bandwidth.

Keywords: *Context Information, Mobile Ad-Hoc and Sensor Networks, Communication Protocols, Context Representation, Context Discovery*

1. Introduction

There has been a steady growth in the number of mobile applications that exploit and adapt to a device's context that is normally based upon location, type, technical capability, functions, nearby devices and more general information about the physical environment [1]. For ad-hoc networks there too is a requirement to be able to detect, share and respond to contextual information however, the unpredictability and dynamically changing topology, especially when one introduces mobility, present particular challenges for the reliable and timely dissemination of context information.

This paper introduces a new approach to context exchange within an ad-hoc network. The framework comprises two components, a Context information Base (CiB) which provides context representation and storage, and a Context information Communication protocol (CiComm) used for sharing context.

The remainder of this paper is organized as follows. Related work on context awareness and its application for ad-hoc networks is presented in Section 2. Section 3 introduces our framework with its features and functions. Simulation results are discussed in Section 4 and Section 5 concludes the paper and evaluates the framework.

2. Related Works

The application of the concept of context awareness to a mobile ad hoc and sensor network can be divided into two main categories. Some projects recognize context information as integrated components to provide interfaces for the invocation of upper and lower layers. In these projects, particular environmental parameters and relevant properties are normally retrieved and recorded as context. Additionally, context-aware frameworks have been designed in mobile ad hoc and sensor networks in order to provide a complete solution for the application of context awareness. Both categories are reviewed in this section.

2.1. Context-aware components

Most context-aware components follow Dey's definition [2, 3], which identifies all relevant information that is able to describe the "situation of an entity" as its context. They identified context as explicit parameters, *e.g.*, devices, users, locations, time, the network. Semantic languages such as XML, OWL, etc. were used to represent context information in these designs [4].

A cross-layer routing protocol was designed in mobile ad hoc and sensor networks, where energy consumption is regarded as context to be employed for better route discovery [5]. Energy related information, *e.g.*, TX and RX power consumption, Angle of Arrival (AoA), *etc.*, was retrieved to determine optimized routes. The results showed better performance since more context information had been collected and processed.

A schema was presented to calculate a trust value for nodes in a mobile ad hoc network [6]. The considered factors include previous interactions, observation of present behavior, recommendation from direct paired devices, *etc*. Generally, the entire collection of information can be recognized as context to build nodes trust.

A location-aware algorithm was presented to broadcast messages in a mobile ad hoc network [7]. Different zones were defined based on neighbor positions to allow or deny forwarding. The results indicate better performance than other broadcasting algorithms in low densities.

Other research works involve self-policing reputation mechanism designed to value a node's neighbors [8], a context-aware adaptive routing protocol (CAR) for best forwarding route considering a node's battery level, mobility and co-location *etc*. [9, 10], a context sensitive binding mechanism for better service migration [11], a decision support engine using general Bayesian network approach [12].

2.2. Context-aware Frameworks

Context-aware architectures were designed to represent and share context. Compared to context-aware components, these architectures provide comprehensive context-aware solutions in a mobile ad hoc and sensor network.

A framework of context-aware migratory services based on a Smart Messages platform has been constructed in a ubiquitous environment [13]. In this framework, context information was examined (MonitoredCxt), stored and shared (Context Manager) and evaluated (Validator).

The Context Broker Architecture (CoBrA) provided an agent based architecture featuring contextual information in pervasive spaces. A common context model based on a context-aware message broker was designed to offer interfaces to context-aware applications [14]. A conceptual context-aware model based on a federation of multiple context brokers was created to facilitate context provision and usage efficiently [15].

The ACORD-CS platform [16] supports full deployment of context-aware applications; a meta-model identified potential context information, whilst the ACORD-CS middleware offered APIs to context-aware applications.

Other models include a Reference Model for a MANET environment [17], the LMSS system to provide relevant location information of mobile users [18], a context-aware architecture for Service-Oriented Computing [19].

2.3. Context Awareness and Service Discovery Architectures

Service discovery protocols (SDPs) in ad-hoc networks are designed to automatically discover the presence of services, determine where and who is providing the services and then manage the retrieval and execution of these services. There is no standard definition of a service; Jini explains it as “an entity that can be used by a person, a program, or another service” and gives two example services, *i.e.*, a printing job and a translation process from one word-processor to another [20]. Sharing context information can be regarded as an ad-hoc network service and hence, an SDP protocol can be used for context discovery and exchange.

Two reviews of SDPs in ad hoc networks [21, 22] have independently proposed that they should be considered as directory based and directory-less. Directory based SDPs use a directory server to maintain a database of devices and their services; this database can be further classified as either distributed or centralized. Directory-less SDPs discover services by sending broadcast or multicast requests to neighboring devices. In general a directory based SDP, *e.g.*, Jini and DSDP [23], favors large scale networks with low levels of device mobility whilst directory-less SDPs are more suited to small scale networks or networks with high levels of device mobility. Another example is that of the Service Location Protocol (SLP) which has been adapted for use in mobile ad-hoc networks, resulting in the creation of SLPManet [24, 25].

3. A New Approach to Context Representation, Discovery and Sharing

In mobile ad-hoc networks devices can exchange context if their behavior and attributes can be justified and decided upon by locally retrieved and remotely shared context information. To enable the exchange of such contextual information we propose a method comprising three parts: a representation model, a context information repository and a communication protocol. The model defines context information in an ad-hoc network environment. It introduces a scheme for context representation and establishes a hierarchical structure to categorize context parameters. The predefined context parameters can then be maintained and shared via the repository and communication protocol.

3.1. Context Representation Model

In terms of an ad hoc environment, context is any information that can be used to characterize the status of an entity. Here an entity can be any object and its status specifies its identity, properties and the proximity of its neighbors.

Five basic interrogative dimensions, *i.e.*, Who, When, Where, What and How are used to categorize context information. These dimensions reflect the understanding of a mobile ad-hoc network and retrieve all aspects within it. Context parameters are predefined in the structure to form a hierarchical view underneath each dimension. Each context parameter is given an index number in a dotted format to indicate its depth from the top of the interrogative dimension.

The hierarchical design and the index scheme aim to reduce the complexity of context representation and make sharing context information consistent in an ad-hoc network. In this paper, parameters are predefined within the CiB for context exchange within the NS2 environment.

3.2. Context Information Repository

Context information Base (CiB) is designed to store context parameters. Two data structures are designed in the CiB. A CiSchema is used to maintain the structure of context information underneath the five interrogative dimensions; whereas a CiData is used to save particular values of context information. A typical CiB design of a PDA is shown in Table 1.

Table 1. A Typical CiB Design Containing Context Parameters of a PDA

CiSchema		CiData	
Index No.	Name	Index No.	Value
1.1.2	ID	1.1.2	001573AF6E2C
1.2.2	Description	1.2.2	“PDA #1”
3.1.2	Position	3.1.2	411 Computer Building, NUIST, 210044
4.1.1	Battery level	4.1.1	54%
5.1.1	Conn. Type	5.1.1	Wi-Fi

A CiB only contains sufficient context information for the mobile device it resides in. Therefore the size of a CiB depends on the device movement and communication with others. When two devices meet, they first share the index numbers of the context parameters that it maintains in their own CiSchema. On reception of this information, two entries are created in the local CiData. A [1.3.x.1] entry saves the sender’s identity; whereas a [1.3.x.2] entry saves the list of index numbers. Here x is a positive integer maintained by the receiver; it is initiated from 1 and incremented or decreased by 1 whenever remote context information needs to be added or removed. At this point, a device can collect what context parameters its neighbors can provide, but does not yet know the actual value of these parameters.

When a context parameter is requested explicitly and responded, three more entries are created in the receiver’s CiB. Two entries in the CiData are first copied to the CiSchema, and then [1.3.x.y] is created in the CiData, where y is the index number of the retrieved parameter.

A CiB can be tailored to fit different ad-hoc network environments. In our work, the CiB is implemented as a linked list to reduce the computing and storage load on mobile nodes.

3.3. Context information Communication Protocol

We have developed a dedicated protocol called CiComm that operates on top of the Logical Link layer to provide an efficient means of exchanging context information between devices. Six protocol packets are defined in the CiComm, involving two beacon packets, Beacon_HB and Beacon_RQ, and four data packets, SHARE, REQUEST, REPLY and UPGRADE. All CiComm packets have a 13-byte header, containing 6-byte source and destination address, and 1 byte to differentiate packet type.

Two phases, Deployment and Retrieval are conducted during the communication. In the Deployment phase, a Beacon_HB packet is broadcast periodically. A Beacon_RQ packet is then returned if two devices are new to each other. Finally, a SHARE packet is transmitted containing index numbers of context information that the device has. At the end of the Deployment Phase, each node will receive its active neighbors' sharing information. A heart-beating timer is set in a node to ensure the transmission of Beacon_HB packets, which consequently commences the Deployment Phase.

The Retrieval Phase aims to get exact values of particular context information from specified nodes. A REQUEST packet is generated to acquire detailed context information. A REPLY packet is then generated with the requested value. The reception of the REPLY packet will cause CiB updates.

No strict dependencies are set on either of the phases; that is, either of the two phases can be started without the completion of the other one. The detailed process on both phases can be found in [26].

4. Performance Evaluation

The performance of our new framework has been evaluated using the NS-2 network simulator. A new module has been created in the NS-2 to provide the functionality of both the CiB and CiComm. This was integrated on top of the Logic Link layer. Local context information is retrieved from three internal modules, MAC, Logic Link and Mobile Node, and shared with others via CiComm packets.

4.1. Validation

Validation of the CiB and CiComm modules in NS-2 comprised establishing a mobile ad-hoc network environment and monitoring how a node is able to acquire and maintain its context information. Figure 1 shows an example scenario comprising one mobile node interacting with ten static nodes where the proximity of devices is expressed by enclosing directly connected nodes together and the acquisition of context information is shown in which the first line reveals where the context information is from, and the second line, having double colons, shows the exact requested parameter. The movement of the mobile node, i.e. node 0 at certain time intervals is illustrated in Figure 2. Four key times are shown for the mobile node's position, and its interaction with its neighbors. The contents of CiData are listed next to the corresponding topologies. For each CiData, the local context information is shown in bold, and any modifications are shown in italics.

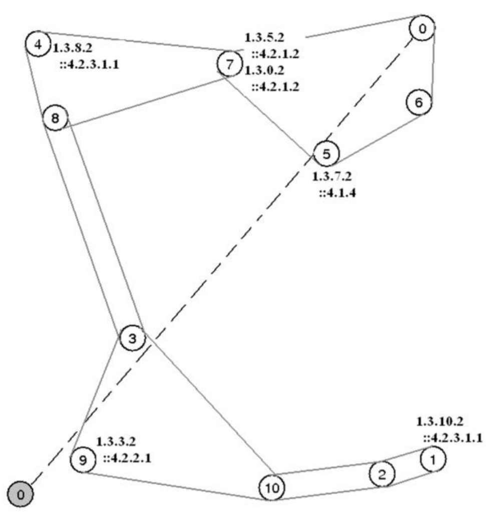


Figure 1. Initial Topology and CiSchema of Designated Mobile Devices. The Movement of Node 0 has been Shown in a Dash Line

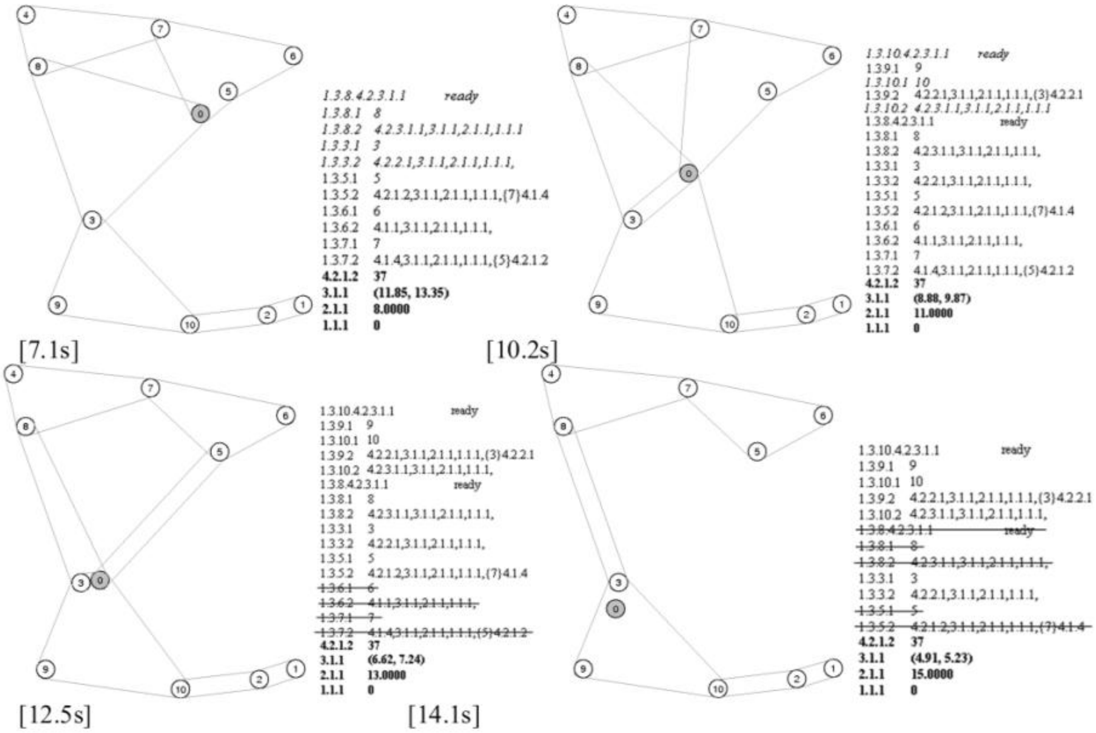


Figure 2. Changes of CiData of Node 0 at critical intervals. With the movement of Node 0, it joined into different ad hoc networks, and learnt context information from its neighbors. When it left a network, corresponding context information was removed from its CiB

This scenario proves that the CiB and CiComm modules can gather, store and share context information in an ad-hoc network. Hence, this simulation provides confidence in the integrity of the underlying principles and functionality of the modules in terms of the initiation of the CiB module, the random settings of local context information and those to be requested, and the exchange of context parameters through the CiComm protocol. From this point it is essential to assess the overall performance of the new framework and to benchmark it with alternative approaches.

4.2. Performance

A key performance metric for any context exchange system is to determine the overall success of how well nodes are able to acquire and maintain accurate contextual information from their environment. To assess this, we define the Overall Discovery Success (ODS), which comprises the Discovered Context (ODS-DC) that indicates the ratio that services are discovered via the reception of reply packets and Cached Context (ODS-CC) that is the ratio that services are discovered in a device's local cache.

Mobility models chosen for these scenarios are defined in [27] and summarized in table 2. They are used to specify the initial positions of mobile nodes and their movement (i.e. speed and direction) during the simulation.

1. Random Waypoint: A random pause period is given when a node in this mobility model needs to change its destination and speed. Furthermore, the chosen destination in this model is mostly close to the center of the simulation area, or needs the mobile

node to travel through the center. The scenarios including conference, PAN, Vehicle Roadside and Vehicle Passengers use this model.

2. Nomadic: A group of mobile nodes in Nomadic model follows a reference point. The difference from the Pursuit model is these mobile nodes move randomly around the reference node, instead of chasing it at the same pace.
3. Random Direction: Nodes in this mobility model only change their destinations and speeds when they travel to the edge of the simulation area. This model effectively spread mobile nodes evenly in the simulation area. The Rescue scenario uses this model.
4. Pursuit: In this mobility model, a group of mobile nodes follows a given target to simulate a policy pursuit event; it is hence used in the Pursuit scenario.
5. Column: A group of mobile nodes in this mobility model forms a line and moves forward. The March scenario uses this model.
6. Random Walk: Random direction and speed are configured in this mobility model with no requirements. The Combat scenario uses this model.

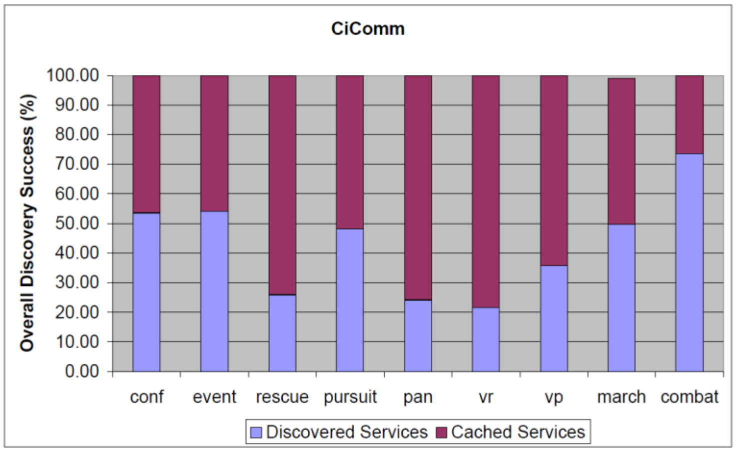
Table 2. Scenarios Designed for the Simulation

Scenario	Simulation Area (m^2)	Node No.	Context Provider /Consumer	Mobility Model
Conference	50 x 30	40	10/10	Random Waypoint
Event	600 x 600	40	10/20	Nomadic
Rescue	1500 x 1500	100	15/5	Random Direction
Pursuit	1500 x 1500	10	5/5	Pursuit
Pan	300 x 300	20	15/5	Random Waypoint
Vehicle Roadside (VR)	1500 x 1500	80	38/12	Random Waypoint
Vehicle Passenger (VP)	10 x 3	6	4/2	Random Waypoint
March	1500 x 1500	50	25/25	Column
Combat	3000 x 3000	250	25/75	Random Walk

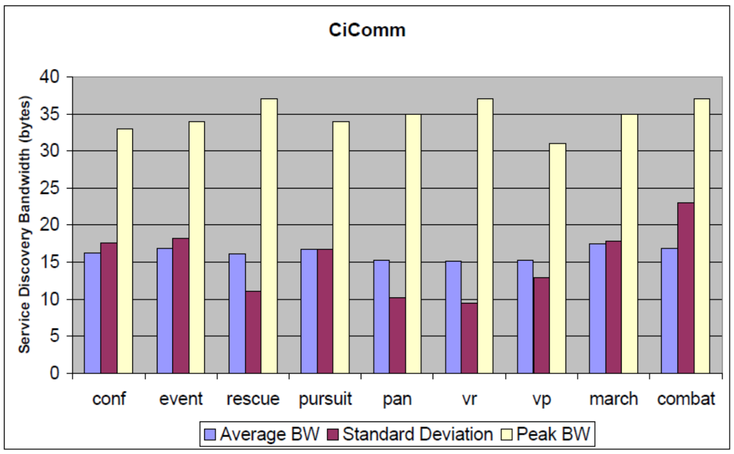
Figure 3(a) examines the ODS where it can be seen that our approach achieves an overall success of 100% in almost all scenarios. This is due to the fact that in our approach discovery transactions are between direct neighbors and even if context information of an indirect neighbor is requested, the cached information from the direct neighbor is provided. Especially, the ratios of ODS-DC in the Rescue, Pursuit, Pan, VR, VP and March are less than 50% which implies that in most scenarios context information has been cached and does not need to be (and is not) requested again.

The Context Discovery Bandwidth (CDB) is the peak and average bandwidth consumed when first discovering context. Figure 3(b) depicts that our approach consumes no more than 40 bytes across all scenarios. This is achieved because the representation model that we use offers an efficient method to represent context information, which causes less contextual data to be transmitted.

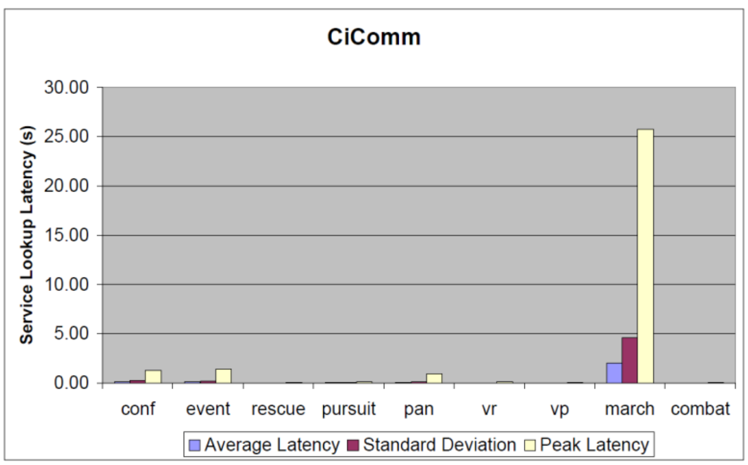
The Service Lookup Latency (SLL) in Figure 3(c) calculates the duration between the time that a request packet is sent and an appropriate reply packet is received. According to the figure, less than 1.5 seconds are spent to complete a lookup transaction in all scenarios, except the March scenario, where more than 25 seconds are spent when the Peak Latency is calculated. High latency is used in the March scenario due to the high coupling level happening in the scenario.



(a) Overall Discovery Success



(b) Service Discovery Bandwidth



(c) Service Lookup Latency

Figure 3. Performance evaluation: (a) overall discovery success rates of each scenario; (b) context discovery consumption in bytes; (c) Service Lookup Latency in seconds

The context exchange method is based on the principle of requesting context information from immediate neighbors. This limits the performance of the context exchange method in large-scale networks since it can take a long time to traverse the entire network. Nevertheless, when a small-scale mobile network is concerned (in our simulation scenarios, no more than 25 context providers were simulated), the results using our method indicates high overall discovery success ratio and low bandwidth usage.

5. Conclusion

In this paper, we present a new approach to context representation, maintenance and exchange in mobile ad-hoc networks, containing a representation model, a Context information Base (CiB) and a Context information Communication protocol (CiComm).

Our method aims to achieve the discovery and retrieval of relevant information, to maintain such information in each device and to adapt to changes within a dynamic networking environment. The method has been simulated in NS-2, and demonstrated its efficient performance in the overall discovery success rate, context discovery bandwidth and service lookup latency it consumes.

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Authors

Qi Liu

BSc (2002), MSc (2006), PhD (2010) is an appointed Professor at the Nanjing University of Information Science and Technology. His research interests include context-awareness, data communication in MANET and WSN, smart home and energy efficiency. He also devotes time to WSN solutions on intelligent agriculture in protected field. He is a member of IEEE and ACM.

Nigel Linge

BSC (1983), PhD (1987) is a Professor of Telecommunications at the University of Salford. He is an electronic engineer by profession and has research interests in network design, context aware information systems, communication protocols, mobile systems and practical applications of networking technology in areas such as energy and building monitoring. He also devotes time to the preservation and dissemination of the history of telecommunications and provides external advice to organization on their heritage strategies. He is a Fellow of the IET and BCS.

Wu Huaiguang

Wu Huaiguang received PhD degrees in computing from Wuhan University in 2011. Since 2011 he has been in the School of Computer and Communication Engineering at Zhengzhou University of Light Industry. His research interests include formal methods, software engineering, and algorithms.