A Peer-to-Peer Overlay Approach for Emergency Mobile Ad Hoc Network Based Multimedia Communications

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ABSTRACT
Overlay networks are located on top of the physical network and are generally favored for the implementation of peer-to-peer (P2P) networks providing services such as voice over IP (VoIP) communications. The operation of the overlay network results in the creation of routing data packets in the network layer. This paper considers the possibility of employing an overlay network for the Mobile Ad hoc NETwork (MANET) architecture in the intention of deploying a P2P network service for extreme emergency cases as described in the EU-FP7 PEACE[1] project. The structured overlay network for the underlying MANET network, proposed in this paper, is built on Bamboo [12] which has been proven to be more efficient than other methods in literature. A study is carried out, using the network simulator ns-2, in order to demonstrate that the proposed enhanced overlay solution has less overhead, and that it has the potential to be used in MANETs for reliable data routing.

General Terms
Algorithms, Measurement, Performance, Design, Experimentation.

Keywords
Ad hoc networking, peer-to-peer, overlays, emergency

1. INTRODUCTION
The MANET is an Internet Protocol (IP) based wireless network which has no central authoritative entity. Therefore, the nodes within MANET could assume the role of a source, a destination or a relay which routes packets from the source node to destination node for multihop communications. Consequently, node mobility is possible in MANETs which could be deployed swiftly when required. MANETs have attracted a lot of attention in the wireless research community because features such as security [9], mobility management, effective routing, data transport, power management, and quality-of-service (QoS) provisioning [10][11] are crucial in cases such as extreme emergencies (e.g. forest fires and the terrorist attacks). In such cases, the public communication networks could be either saturated or destroyed and communications among emergency workers could be supported using MANETs

An overlay network [2] is a virtual network which can operate on top of a physical network and could facilitate the deployment of multimedia P2P services such as P2P VoIP. The virtual P2P overlay networks would facilitate provisioning of multimedia services in MANETs where node mobility, lack of any centralized organization or hierarchical control could be complex problems. The P2P overlay network would provide a good substrate for large-scale data sharing, content distribution and application-level multicast applications. Especially, P2P overlays provide features which include selection of nearby peers, redundant storage, efficient search/location of data items, data permanence or guarantees and hierarchical naming. The overlay could potentially offer an efficient routing architecture which would be self-organized, scalable, and robust. These characteristics would introduce fault tolerance, load balancing and explicit notion of locality in MANETs. Fault tolerance is especially important in MANETs because the physical network is dynamic (e.g. there are regular joining and leaving of nodes). The advantages due to the integration of a P2P overlay in MANETs are particularly important in the context of extreme emergencies for rescuers requiring sharing of text and multimedia information in an effective and efficient manner. This study will concentrate on the possible integration of an overlay network on top of the physical MANET topology where data is reliably routed in the network with minimal total routing overheads. The paper is organized as follows. Section 2 gives motivation for the proposed overlay integration to the MANET topology. Section 3 details our proposed methodology of incorporating a structured overlay into the MANET topology. We present the simulation results regarding our proposed methodology evaluating the performance and the overhead, in section 4. Section 5 describes related work, and section 6 draws conclusions based on our findings.

2. MOTIVATION
A P2P overlay network requires that the physical network would maintain actual routes to nodes participating in the overlay. The MANET routing protocol would then be responsible to route any type of packets which need to be exchanged between or among the overlay nodes. MANET routing approaches include proactive

[1] PEACE is a partly funded EU project. For more info visit: http://www.ict-peace.eu.

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routing such as Optimized Link State Routing (OLSR) [10], reactive routing such as Ad hoc On demand Distance Vector (AODV) [10], geographical and hybrid routing. The aforementioned protocols are among the most popular protocols for MANETs and are being considered as possible standards.

We consider the Pastry [2] overlay structure as an example where the physical topology and logical topology are not tied together. Despite the fact that Pastry has the potential to route to a given key within an overlay of N nodes in [$\log_2 N$] steps, there remains the actuality that Pastry does not account for intermediate nodes. In this case the actual number of physical steps can increase almost indefinitely in large-scale networks. This may pose no problem when bandwidth is plentiful and the overhead for routing such lookups is negligible. However in the context of MANETs, we cannot neglect such overheads for the following reasons;

- The links between MANETs can be weak due to many factors (eg. physical obstructions). This means the less bandwidth we use in overhead, the less packet loss we can induce.
- There are no backbones akin to those in fixed networks within the MANET infrastructure which can handle vast quantities of traffic. In MANETs the traffic is evenly spread throughout the network.
- Links between nodes of the MANET are usually of lower bandwidth compared to their internet counterparts. This is primarily due to the bandwidth in MANETs being by no means guaranteed due to constraints such as distance and hardware
- Device properties must be addressed. Overheads may seem reasonable on one hardware platform but may incur heavy packet loss if the same routing operations are performed on devices with less power

The aforementioned problems require us to develop new ways of routing in P2P overlays, however first one must consider the structure of the overlays themselves. In modern P2P overlay research we can see three main areas of study, which propose distinct ways of structuring P2P overlays and these are detailed below.

Firstly, unstructured overlay networks are organized in a random manner either flat or hierarchically. Queries are executed by means of flooding, random walks or expanding-ring Time To Live (TTL) techniques. When a peer receives a query it will initiate the search on its own local content. This allows the execution of more complex queries and search strings, for example using wildcards. An example of an unstructured overlay network implementation is the Gnutella system [3].

Secondly, structured overlay networks are controlled in a more organized manner. When nodes join or leave the overlay they must adhere to strict rules which govern how information must be distributed. There are also strict rules on lookup queries where the overlay network utilizes its own routing algorithms at the application layer. Information is distributed evenly throughout the network and lookups emanate from the lookup node to the target node using routing based on node identifiers. An example of a structured overlay network implementation is Chord [4].

Thirdly, in hybrid overlay networks users perform lookup queries at a central server separate from the overlay network. Once the client has queried the central server, the latter responds with a list of IP addresses containing the relevant data in the overlay network. The advantage of this system is that complex queries can be executed on the central server and subsequently found in the overlay by the client. An example of an implementation of this system is the BitTorrent [5], which makes use of a 'tracker' to keep track of IP's of nodes containing the relevant data.

3. Common Group Aliasing

Common Group Aliasing (CGA) refers to the process we propose for creating an intimate relationship between the overlay network, and the underlying physical network topologies. In this section we discuss our approach to the aforementioned problem of topology mismatch.

3.1 Our Approach

When designing a P2P overlay network for use within MANETs one of the major considerations is what type of overlay network structure to use, be it unstructured, structured or hybrid. In this case we propose a structured overlay for use within MANETs as detailed below.

3.1.1 Proposed Distributed Hash Table

In this work, we use a structured Distributed Hash Table (DHT) P2P overlay network. The reasons we chose this architecture, such as in [1], over the previously mentioned is the fact that structured overlays guarantee that all queries sent by a node will yield the full results as long as the information exists within the overlay network.

The DHT we propose in this paper is based on a modification of a Pastry approach called Bamboo [1]. Pastry makes use of Plaxton-like prefix routing, which results in an architecture that is completely self-organizing and decentralized. In Pastry each peer routes client requests and interacts with usually one or more applications. Each peer in the overlay is assigned its own 128-bit identifier called a NodeID. In a network containing N peers, Pastry routes to the peer which is numerically closest in its NodeID to a given key, in less than $\log_B N$ steps (under normal operation $B = 2^b$ and typically $b = 4$). In Pastry the NodeID and keys are a sequence of numbers with base B. Once Pastry knows the key is looking for, by for instance hashing a piece of meta-data, it routes the message to the peer which has a NodeID numerically closest to the given key.

With Bamboo the aim was to take an existing DHT such as Pastry and study the algorithms used in order to refine the architecture. To this end a more efficient and reliable overlay network is created. In [1] Bamboo is proposed by exploring various design tradeoffs and their effects on its ability to handle churn (peers joining and leaving the overlay network). The design tradeoffs analyzed look at, reactive versus periodic recovery when a neighbor in the current peers routing table fails (this usually happens when peers leave the network), the calculation of the most efficient timeout for lookup messages and proximity neighbor selection.

3.1.2 CGA Algorithm

In this section we layout our proposal for CGA discussing the main factors involved in the algorithm in detail and and how they can be incorporating within the concept of MANETs. The initial algorithm was partly based on the work published in [6], however we have looked to refine these processes and propose to use the

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Bamboo DHT in contrast to the Pastry DHT proposed in [6] towards the enhancement of the performance.

3.1.2.1 Entities

In CGA we define entities as different classes of devices. In CGA we must consider three different types of entities and how they interact in the overlay network. These entities are

- Mobile devices with enough power to route and forward packets while maintaining minimum packet loss due to hardware constraints.
- Devices where power is limited and therefore resources are less abundant. In these cases overlay routing and packet forwarding is inefficient due to packet loss caused by hardware constraints.
- Intermediate devices, which do not participate in the overlay. However, these are still part of the underlying MANET and they will therefore be used to route packets using network layer routing protocols such as AODV and OLSR.

In CGA we must differentiate between these devices in order to serve queries more efficiently. We assume that when building an implementation for a specific platform, e.g. x86 or iPhone, the software itself will know if it is a low powered device like an iPhone or a device with more resources such as an x86 architecture based laptop.

To create more efficient overlay routing and to save vital battery power on low powered devices such as PDAs and smart phones, we propose these devices to be classed as selfish nodes. Such nodes would not route packets in the overlay network primarily to save precious battery power but also because of their small antenna which is prone to packet loss.

At the network layer, selfish nodes could be regarded as unfavorable routing paths and routing protocols could be enhanced to choose alternative routes. However, if no alternative paths exist, the selfish nodes could be used as relays. Such a scheme would preserve a higher overall network energy level prolonging network life as well as offering a better quality of service (QoS) for data communications.

On the other hand, devices which have sufficient resources will be enabled in the CGA architecture to forward and route lookup queries where necessary. This will be achieved using the Bamboo implementation where lookups are routed to the node with the nearest node ID prefix to the specified key ID prefix. However there are differences, which are discussed in the following sections.

3.1.2.2 Common Grouping

Common Grouping (CG) refers to the process of grouping devices, which are also closed physically in the underlying physical network, together in the P2P overlay network,. To achieve this goal we propose that the 128-bit node ID space is partitioned equally. For example nodes beginning with the prefix ID 1.. 2.. 3.. 4.. 5.. 6.. 7.. 8.. 9.. will be partitioned into common groups based on their physical position in the overlay network. This is realized through the use of *marker nodes*. These are nodes whose own node ID prefix is numerically closest to a set of *marker keys*. The marker keys in the above partitioned space would be 1000… 2000… 3000… 4000… 5000… 6000… 7000… 8000… and 9000.

To establish marker nodes in the creation of the overlay, nodes initially send a *marker request* to the marker key closed to their node ID, for example a node with an ID of 2349… would send a marker request to the marker key 2000…. This request would then be routed to the node closest to the marker key using the normal Bamboo routing method to distribute the keys. The marker node is therefore determined by the node, which does not have a node closer to the marker key in its leafset. Once the marker request has arrived at the node with the ID closest to that of the marker key, the node then declares itself as a marker node. Initially this is accomplished by the node changing its node ID prefix to that of the marker node.

Once a marker node has been established it then proceeds to send out a periodic marker beacon. When a node becomes a marker node primarily it does not have any nodes within its CG set. Therefore we propose that initial marker nodes send out a marker beacon with a two-hop TTL. The beacon is a basic packet, containing the ID of the marker node, along with information relating to the distance the beacon has travelled in hops.

If a node receives a marker beacon and it is not part of any CG will part the overlay network and then rejoin the network with its new ID. The new ID is calculated as its original node ID with x digits added to the start to match the marker node's first x digits. The digits are added instead of replaced to avoid node ID duplicates.

Once a marker node has a CG set of more than *N* nodes it will then switch to only sending marker beacons to nodes within its CG. Nodes participating in a CG will then forward the marker beacon to any nodes within a one-hop radius in the physical underlying network. If a node receiving a marker beacon in this situation is not already participating in a CG it will immediately join the CG in the aforementioned manner.

If a node receiving a marker beacon is already participating in a CG however, it will consider by examining the hop count how far the beacon has travelled. If the hop count of the marker beacon is less than that of its hop count to its current marker node, it will leave its current CG and rejoin the overlay in the new CG. Once the marker beacon has reached a node not participating in the CG from which the node was sent, it will process the beacon information and then drop the packet. This is a required because it is not desirable to broadcast a marker beacon throughout the whole network, hence one hop from the CG should suffice in keeping the CG nodes physically close to each other both in the overlay network, and the underlying network.

Nodes send periodic probes to their marker nodes to check if the marker node has left the network or has failed. If a marker node does not respond for a predefined number of probes, the marker node is regarded as having left the overlay P2P network. The current node will then immediately send a marker request. The node which then receives that marker request will become the new marker node.

3.1.2.3 Routing process

Marker nodes in CGA know the node ID of the other marker nodes in the overlay, as it is a prerequisite that the ID space be partitioned into equal marker keys. Therefore each marker node will send a marker IP request to each of these marker nodes' IDs

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at periodic intervals. The subsequent replies will be added to the marker group table which lists the IPs for current marker node IDs in the overlay.

The routing process in the CGA overlay is much the same as in Bamboo. However instead of nodes maintaining ‘neighborhood’ node sets, a node’s leafset is expanded because leafnodes should be close to it in the physical network due to the CG process. Additionally nodes keep track of their marker node’s ID. If a query is requested first the node will look in its leafset table if no matching nodes are found and the query is then forwarded to its marker node. If the closest numerically node ID to the queries key ID lies within the CG, the marker node will simply forward the query to the corresponding node. If the key ID for the query however lies in another CG the marker node will forward the query to the marker node responsible for that CG, who will then forward it directly to the node responsible for the key ID.

When a node probes its marker node, the marker node adds the nodes ID into its CG table along with a TTL. Therefore every marker node automatically knows the ID’s of all nodes within its CG. If a probe is not received within the TTL of the entry, the node is considered having left the network. However, we must still maintain leafset tables due to churn.

The routing state for the underlying network is $2 \cdot b + k$ bound where b is equal to the TTL of the marker beacon transmitted by the marker node, and k is equal to the number of hops between two marker nodes. The routing state for the overlay network is denoted as $2 \cdot b + 1$.

3.1.2.4 Topology

We believe our proposed algorithm to create a topology in the overlay P2P network, which much resembles that of the underlying MANET on the network layer. The notion of using marker nodes to route queries and allowing the network layer protocol to find the best route between marker nodes should create optimal routing of queries. However the bandwidth needed to route such queries must be examined. From such studies we can develop mechanisms to allow for greater scalability. For instance, we can illustrate this by increasing the number of marker nodes when the total number of nodes in the overlay reaches a predetermined threshold. The topology of our proposed P2P overlay is shown in Figure 4. Due to the fact that in emergency situations, groups of emergency service workers are generally working in close proximity to each other, we believe this to have a major impact in lookups between workers of specific emergency services, which will in turn decrease lookup times on the overlay network as whole.

4. SIMULATION RESULTS

4.1 Simulation

Our implementation of the CGA in ns-2 was based on the source code from [12]. The generation of landmark keys, initial assignment of these keys to nodes, the virtual and physical topology as well as mobility patterns were constructed before the start of simulations. In addition, the initial physical and overlay network clustering configurations are carried out before simulations. The topology changed dynamically due to node mobility with simulations over a MANET using the AODV and OLSR routing protocols. The IEEE 802.11b MAC protocol in RTS/CTS/Data/ACK mode was used. The simulated scenario was a 1000m*1000m area. (e. g. in a forest fire scenario).

4.2 Results

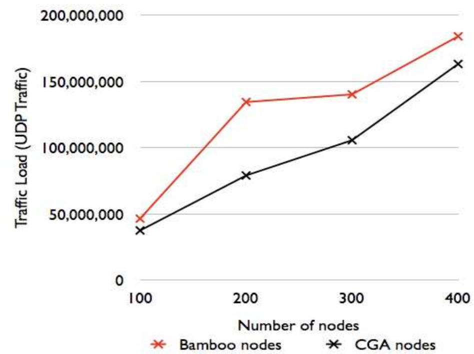

Figure 1. Graph showing total traffic

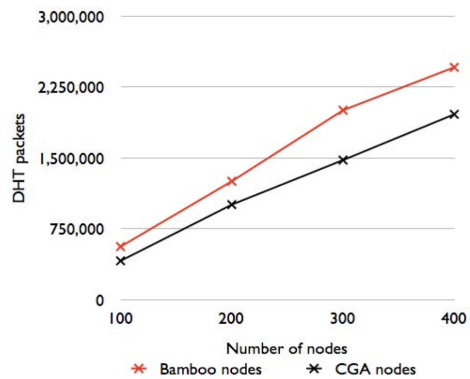

Figure 2. Graph showing DHT packets vs nodes.

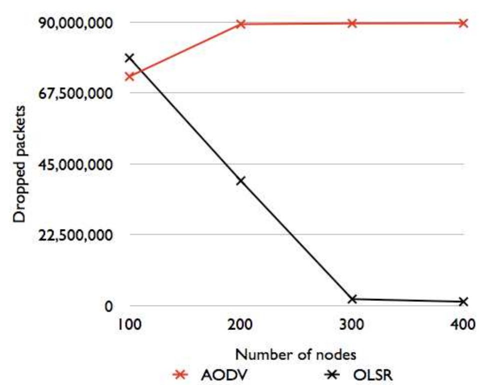

Figure 3. Graph showing Dropped packets vs nodes.

CGA improves performance in MANETs as shown in figures 2 and 3. These figures clearly demonstrate that the CGA technique requires fewer packets and less traffic to be exchanged in the battery constrained MANET environment to achieve the same lookup query resolution as Bamboo. Results also show that for MANET routing, OLSR is a better option than AODV in terms of reliability as we illustrate in figure 4. There are fewer packet losses when OLSR is used for routing the overlay traffic than in

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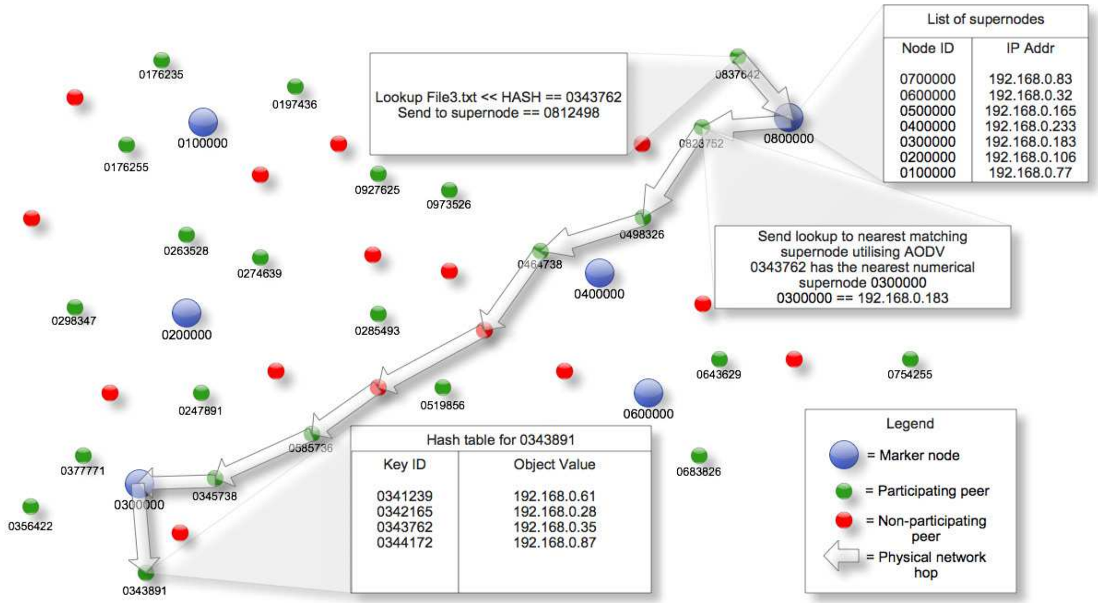

Figure 4. Lookup topology of a DHT with CGA.

AODV case. This is even more distinct for bigger networks where the overlay generates more traffic and packets. This is probably due to the readily available proactive routes as opposed to the on demand AODV route establishments, which encourages queuing especially for low mobility MANETs.

5. CONCLUSIONS

Our proposed CGA overlay for MANETs using OLSR could provide a reliable and efficient method to implement a DHT. If marker nodes are simply unable to handle the amount of traffic we have two choices; increase the number of marker nodes, or just have normal Bamboo routing. The former will of course increase the number of average hops, but distribute the load throughout the network. This case should be investigated in future work. Further refinement of the optimal parameters of the algorithm should also be further investigated such as optimal thresholds and TTLs to increase scalability.

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7. REFERENCES

[1] B. Y. Zhao, L. Huang, J. Stribling, S. C. Rhea, A. D. Joseph, and J. D. Kubiatowicz, “Tapestry: A resilient global-scale overlay for service deployment,” *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 1, pp. 41–53, 2004.

[2] K. Lua, J. Crowcroft, M. Pias, R. Sharma, and S. Lim, "A survey and comparison of peer-to-peer overlay network schemes," *Communications Surveys & Tutorials, IEEE*, pp. 72-93, 2005.

[3] M. Ripeanu, "Peer-to-peer Architecture Case Study: Gnutella Network", in Proceedings of the First International Conference on Peer-to-Peer Computing, 99 (2001).

[4] I. Stoica, R. Morris, D. Karger, F. Kaashoek, and H. Balakrishnan. “Chord: A Scalable Peer-To-Peer Lookup Service for Internet Applications.”, In Proc. of the ACM SIGCOMM 2001 Conference, San Diego, CA, 2001.

[5] B. Cohen, "Incentives Build Robustness in BitTorrent", in Proceedings of First Workshop on Economics of Peer-to-Peer Systems, June 2003, http://www.bittorrent.com/bittorrentecon.pdf.

[6] T. Heer, S. Gotz, S. Rieche, and K. Wehrle, “ Adapting Distributed Hash Tables for Mobile Ad-hoc Networks ,” Proceeding of Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops , pp.173 – 178, 2006.

[7] T. Zahn and J. Schiller. “MADPastry: A DHT Substrate for Practicably Sized MANETs.”, In 5th Workshop on Applications and Services in Wireless Networks (ASWN 2005), Paris, France, June 2005.

[8] G Millar, C. Politis, " Architectures for Multiple Peer-to-Peer Overlays in MANETs in Emergency Situations", 22nd Wireless World Research Forum (WWRF), May, Paris, France, (2009)

[9] E. Panaousis, C. Politis, "Securing Ad-Hoc Networks in Extreme Emergency Cases", WWRF 2009, May, Paris, France, (2009)

[10] T. A. Ramrekha, C. Politis, "An Adaptive QoS Routing Solution for MANET Based Multimedia Communications in Emergency Cases.", 1st International ICST Conference on Mobile Lightweight Wireless Systems, May, Athens, Greece, (2009) abstract

[11] Z. Li and P. Mohapatra, "Qron: Qos-aware routing in overlay networks," *Selected Areas in Communications, IEEE Journal on*, vol. 22, no. 1, pp. 29-40, 2004.

[12] O. Rensfelt, L. Larzon, “A bandwidth study of a DHT in a heterogeneous environment”, 4th Swedish National Computer Networking Workshop SNCNW, (2006)

Digital Object Identifier: 10.4108/ICST.MOBIMEDIA2009.7860
http://dx.doi.org/10.4108/ICST.MOBIMEDIA2009.7860