Chapter 1

Introduction

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1.1 Introduction

Recent technological advances have enabled a push towards wireless systems in every aspect of technology. The advances in network infrastructures, availability of wireless applications, and the emergence of mobile devices such as portable computers, PDAs and cell phones fuelled an unexpected growth in the wireless arena. The current wireless systems can be classified into two broad categories based on how the network is established: infrastructure based network and infrastructure-less networks. The infrastructure based networks include cellular networks and wireless LAN. The base stations in cellular networks and access points in wireless LAN act as the infrastructure for these types of networks. The connection is established in one hop between the mobile nodes and the local base station in cellular networks. In contrast, an infrastructure-less network is formed dynamically through the cooperation of an arbitrary set of independent nodes. These mobile nodes make their decisions independently, based on the network situation without using a preexisting infrastructure. The flexibility and distributed architecture of these networks made them applicable to areas in which a prior deployment of network infrastructure is impossible. Certain environments where ad hoc networks are used include military and rescue operations, natural disasters or places where deployment of wired networks is not possible. Furthermore, ad hoc networks play an important role in commercial applications such as automotive safety improvement, provide passengers with information and entertainment, smoothen traffic flow on the roads etc. The ad hoc network can be realized by different networks such as body area networks (BAN), vehicular ad hoc networks (VANET), wireless networks (varying from personal area network to wide area network), and wireless sensor
networks (WSN). However, the design of these networks poses various challenges due to the multi-hop nature and lack of fixed infrastructure.

1.2 A Review of Ad hoc Network Evolution

The concept of mobile ad hoc networking can be traced back to the Defense Advanced Research Projects Agency (DARPA) Packet Radio Network (PRNET) project in 1972 [Freebeverset, 2001]. PRNET had a distributed architecture consisting of a network of broadcast radios with minimal central control. A combination of Aloha and Carrier Sense Multiple Access (CSMA) channel access protocols are used to support the dynamic sharing of the broadcast radio channel. It also supports multi-hop store-and-forward routing techniques which remove the radio coverage limitation and enable multi-user communication within a very large geographic area.

The successful demonstrations of the PRNET proved the feasibility and efficiency of infrastructure-less networks and their applications for civilian and military purposes. DARPA extended the work on multi-hop wireless networks through the survivable radio networks (SURAN) project that aimed at providing ad hoc networking with small, low-cost, low-power devices with efficient protocols and improved scalability and survivability. However, interest in this area grew rapidly in the nineties due to the popularity of a large number of portable digital devices such as laptop and palmtop computers, and the common availability of wireless communication devices.

The rising popularity of Internet and the development of internetworking protocols for mobile ad hoc networks which operates in license-free radio bands, lead to the development of a working group within
1.2. A Review of Ad hoc Network Evolution

Internet Engineering Task Force (IETF) termed the Mobile Ad Hoc Networking (MANET) working group to standardize the protocols and functional specifications of ad hoc wireless networks. The vision of IETF effort in MANET working group is to provide improved standardized routing functionality to support self organizing mobile networking infrastructure. Motivated by the growing interest in ad hoc networking, a number of commercial standards were developed in the late nineties. This includes the IEEE 802.11 physical layer and MAC protocol [Anastasi, 2003], which has since then evolved into the more updated versions. Today, one can build an ad hoc network by simply plugging in 802.11 Personal Computer Memory Card International Association (PCMCIA) cards into laptop computers. Bluetooth [Bisdikian, 2001] and Hiperlan [Mingozi, 2002] are some other examples of related existing products.

Although ad hoc wireless networks are expected to work in the absence of any fixed infrastructure, recent advances in wireless network architectures reveal interesting solutions that enable the mobile nodes to function in the presence of infrastructure [Murthy;2004]. These hybrid architectures which combine the benefits of cellular and ad hoc networks improve the capacity of the system significantly.

The mobile nodes in an ad hoc network utilizes multi-hop radio relaying for information exchange where data packets are transmitted in a store and forward manner from any source to an arbitrary destination via intermediate nodes as shown in Fig. 1.1. Nodes that lie within each other’s transmission range can communicate directly and are responsible for dynamically discovering each other. The transmission range is limited by the energy preserved in the mobile nodes. In order to enable communication between nodes that are not directly within each other's
send range, intermediate nodes act as routers to relay packets generated by other nodes to their destination. Furthermore, the topology of these networks may change dynamically as devices are free to join and leave the network at any time. In this energy-constrained, dynamic, distributed multi-hop environment, nodes need to be organized dynamically in order to provide the necessary network functionality. In addition, these networks are faced with the traditional problems inherent to wireless communications such as lower reliability than wired media, limited physical security, time varying channels, interference, etc.

1.3 MANET Architecture

The MANET IETF working group has been the major reference point for the research activities on pure general purpose MANET. The MANET
1.3. MANET Architecture

![MANET Architecture Diagram](image)

Figure 1.2: A MANET Architecture

IETF working group adopted an IP centric view of MANET that inherited the TCP/IP protocols stack layering with the aim of redesigning the network protocol stack to respond to the new characteristics, complexities and design constraints of MANET [Corson, 1999]. All layers of MANET’s protocol stack were subjects of intensive research activities. Fig. 1.2 gives a layered view of the protocol stack.

As shown in the figure, the research activities in MANETS are grouped into three main areas:

- Enabling technologies;
- Networking;
- Middleware and applications.

In addition, issues like energy management, security and cooperation and
Quality of Service (QoS) span in all layers.

1.3.1 Enabling technologies

Enabling technologies of MANET guarantee direct single hop communications between user’s devices. These include 802.11 families, Bluetooth and Zigbee. Bluetooth technology is a de-facto standard for low cost, short range radio links between mobile PCs, mobile phones and other portable devices. The IEEE 802.11 standard is currently the most mature technology for WLANs. It defines two operational modes—infrastructure based and ad hoc networks. Network interface cards can be set to work in either of these modes but not in both simultaneously. The IEEE 802.11 technology is a good platform to implement single hop ad hoc networks because of its extreme simplicity. It specifies the MAC layer and Physical layer for WLANs in a publicly available ISM bands. Initially, three different physical layer options were provided: Infrared, Frequency Hopping Spread Spectrum (FHSS) at 2.4 GHZ and Direct Sequence Spread Spectrum (DSSS) at 2.4 GHZ. The infrared physical layer is neglected gradually. For the MAC layer two channel access methods were defined. The first method, Distributed Coordination Function (DCF), is used in WLAN and Point Coordination Function (PCF) for ad hoc networks. Among the different IEEE 802.11 variants (Task Groups) like IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11h, IEEE 802.11e, IEEE 802.11c, IEEE 802.11d, IEEE 802.11f and IEEE 802.11i, IEEE 802.11b (Wi-Fi) is the most popular one and is the one used for ad hoc networking.

ZigBee builds on IEEE 802.15.4 standard [Baronti, 2007] which defines the physical and MAC layers for low cost and low rate personal
area networks. ZigBee defines the network layer specifications for star, tree and peer-to-peer network topologies and provides a framework for application programming in the application layer. The IEEE 802.15.4 standard defines the characteristics of the physical and MAC layers for Low-Rate Wireless Personal Area Networks (LR-WPAN). The advantages of an LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life while maintaining a simple and flexible protocol stack.

### 1.3.2 Networking Layer

In network layer, special attention is given to routing and forwarding. It includes the network and transport protocols.

**Network Protocols.** The ad hoc network routing protocols are generally divided into two broad categories: proactive routing protocols and reactive on demand routing protocols [Royer 1999]. Proactive routing protocols maintain consistent, up to date routing information between every pair of nodes by propagating, proactively, route updates at fixed time intervals. As the routing information is usually maintained in tables, these protocols are sometimes referred to as Table Driven protocols. Representative protocols include Destination Sequenced Distance Vector (DSDV) protocol, Cluster head Gateway Switching Routing (CGSR) protocol, Wireless Routing Protocol (WRF), Global Sate Routing (GSR), Optimized Link State Routing Protocol (OSLR), Fisheye State Routing (FSR) protocol and Hierarchical State Routing (HSR).

Reactive on demand routing protocols, on the other hand, establish the route to a destination only when there is a demand for the route. The
source node initiates the route request. Once the route has been established, it is maintained either until the destination becomes inaccessible, or until the route is no longer used or expired. In reactive routing protocols a ‘Just in Time’ (JIT) approach is used to discover routes. The nodes discover routes to destination on demand, i.e., a node does not need a route to a destination until that destination is to be the sink of the data packets sent by the node. Reactive protocols often consume much less bandwidth than proactive protocols, but the delay to determine a route can be significantly higher. Representative reactive routing protocols include: Dynamic Source Routing (DSR), Ad hoc On demand Distance Vector (AODV), Temporally Ordered Routing Algorithm (TORA), Associativity Based Routing (ABR), and Signal Stability Routing (SSR).

**Transport protocols.** TCP was primarily designed to work for a wired network. The error rates in wired networks are quite low and therefore packet loss in these networks is taken as an indication of network congestion. In the case of mobile ad hoc networks, mobility may cause route failures which result in packet loss and increased delays. The TCP misinterprets these losses as congestion and invokes the congestion control mechanisms which will lead to unnecessary transmissions. To improve the performance of the TCP protocol in a MANET, several TCP optimization techniques have been presented over the past few years. For example, techniques have been proposed to minimize the impact of mobility and link disconnection on TCP performance by the use of explicit link failure notification (ELFN) [Holland, 2002], a technique to distinguish between packet losses due to network congestion and other factors such as buffer overflow, transmission errors and mobility by using link connection information [Gerla, 1999]. However, Anastasi, [2000] show
that TCP based solutions might not be the best approach when operating in MANET environments.

1.3.3 Middleware and Applications

Middleware supports development of applications for information access and sharing with considerable flexibility. However, middleware support for ad hoc networks is still in the infant stage. The middleware developed for MANETS are tightly coupled with applications and there is no single general middleware that resolves all problems. STEAM [Meier, 2002], EXpeerience [Bisignano, 2003], EMMA [Musolesi, 2005], LIME [Murphy, 2001], LIMONE [Fok, 2004], XMIDDLE [Mascolo, 2002], MATE [Hadim, 2006] are some of the middleware developed.

1.3.4 Cross Layer Research Issues

In cross layer research issues, special attention is given to energy efficiency, security and cooperation and QoS. These issues cannot be completely implemented inside a single layer, but they are implemented by combining and exploiting mechanisms implemented in several layers.

Energy Efficiency. The mobile node in an ad hoc network has limited power supply and has no capability to generate power. In addition, the mobile nodes must implement all the network basic functions like routing and forwarding. It is therefore vital to have energy efficient protocol design at all layers while designing algorithms for mobile devices. Energy conservation requires a coordinated effort from all related layers, including the physical layer transmissions, the operating system and the applications [Basagni, 2004].
Network security and Cooperation. The ad hoc nature of MANET brings new security issues that are not addressed by the services provided for infrastructure based networks. As the nodes in MANET communicate with each other using the shared broadcast wireless channels, they are more vulnerable to security attacks. Compared to wired networks which have dedicated routers, each mobile node in an ad hoc network may function as a router and forward packets for other peer nodes. As a result, there is no well defined place to implement traffic monitoring or access control mechanism. Furthermore, the distributed and infrastructure-less nature of ad hoc networks makes a centralized security control hard to implement. The existing routing and MAC protocols assume a trusted and cooperative environment. Thus it becomes easier for an attacker to disrupt network operations. In order to ensure a complete security solution for MANET, the mobile nodes must co-operate each other. The cooperation should be in detecting and isolating misbehaving nodes. Table 1.1 gives the possible attacks on MANET at each layer [Yang, 2004].

Quality of Service. QoS is generally defined as a set of service requirements that needs to be satisfied by the network while sending a packet stream from a source to its destination. The network is expected to deliver a set of measurable predetermined service attributes to users in terms of end-to-end performance, such as delay, bandwidth, probability of packet loss, and delay variance (jitter). QoS attributes that are more specific to MANETs include power consumption and service coverage area. The multi-hop nature of ad hoc networks introduces several issues and difficulties for QoS support. These issues include features and consequences [Mohapatra, 2003]. Examples of features include unpredictable link properties, node mobility, and limited battery life, whereas hidden
1.4. MANET Characteristics

<table>
<thead>
<tr>
<th>Layer</th>
<th>Security issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Detecting and preventing viruses, worms, malicious codes, and application abuses</td>
</tr>
<tr>
<td>Transport</td>
<td>Authenticating and securing end-to-end communications through data encryption</td>
</tr>
<tr>
<td>Network</td>
<td>Protecting the ad hoc routing and forwarding protocols</td>
</tr>
<tr>
<td>Link</td>
<td>Protecting the wireless MAC protocol and providing link-layer security support</td>
</tr>
<tr>
<td>Physical</td>
<td>Preventing signal jamming denial-of-service attacks</td>
</tr>
</tbody>
</table>

Table 1.1: Possible attacks on MANET

and exposed terminal problems, route maintenance, and security can be categorized as consequences. Important QoS components in MANETs include QoS MAC, QoS Routing, and resource reservation signaling. The various QoS requirements include throughput, delay, jitter, error rate, battery life etc.

1.4 MANET Characteristics

MANETs inherit the common characteristics found in wireless networks in general which include:

- Packet loss due to transmission errors
- Variable capacity links
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- Frequent disconnections / Partitions
- Limited Communication Bandwidth
- Broadcast nature of the communications

The characteristics specific to ad hoc networks include:

- **Wireless**—Nodes communicate wirelessly and share the same media (radio, infrared).
- **Ad hoc based**—A temporary network formed dynamically in an arbitrary manner by a collection of nodes as need arises.
- **Autonomous and infrastructure-less**—MANET does not depend on any established infrastructure or centralized administration. Each node operates in distributed peer to peer modes, acts as an independent router and generates independent data.
- **Multi-hop routing**—No dedicated routers are necessary; every node act as a router and forward its packets to enable information sharing between mobile hosts.
- **Mobility**—Each node is free to move about while communicating with other nodes. The topology of such an ad hoc network is dynamic in nature due to the constant movement of participating nodes causing the inter communication patterns among nodes to change continuously.
- **Anytime, Anywhere**—Ad hoc wireless networks eliminate the constraints of infrastructure and enable devices to create and join networks on the fly- anytime, anywhere—for virtually an application.
1.5 Application

Mobile ad hoc networks have been employed in scenarios where an infrastructure is unavailable, or to deploy one is not cost effective, or when there is no time to set up a fixed infrastructure. It allows users to access and exchange information regardless of their geographic position or proximity to infrastructure. In contrast to other wireless networks, all nodes in MANETs are mobile and their connections are dynamic. This decentralized character of the MANET makes the networks more flexible and robust. Historically, MANETs were first used by the military as a part of tactical networks to improve battle field communication. Although ad hoc networks were initially used in military applications, a number of non-military applications have emerged due to the availability and advances in mobile ad hoc research. Some examples of these applications include rescue operations, emergency services, communication between vehicles, sensor networks and personal area networks [Basagni, 2004].

MANETs are ideal for crisis management applications such as disaster recovery, where the entire communication infrastructure is destroyed and establishing communication quickly is not possible [Shibata, 2007]. One of the many possible uses of ad hoc network is in personal area networks. Personal area networks are created when a small number of nodes meet spontaneously to form a network for the purpose of teleconferencing, file sharing, or peer-to-peer communication. Sensor Networks [Pandey, 2010] is an adhoc network consisting of a large number of distributed sensor devices, which is densely deployed in remote areas to detect the environmental conditions such as temperature, pressure, humidity, sound, vibration, motion, pollutants etc. Applications of these networks include health monitoring, military surveillance, monitoring household items, animal
tracking *etc.* Mobile ad hoc networks allow rapid network deployment in an emergency situation. Emergency networks can be set up in remote or hostile areas where there is no existing communication infrastructure, thereby assisting relief work and rescue missions. A vehicular ad hoc network (VANET) provides communication between vehicles, roadside equipment and vehicles travelling in close proximity. Data is exchanged between nearby vehicles to provide traffic information and early warnings for accidents and road works. The purpose of vehicular ad hoc networks is to provide a communication network of safety and information for users [Wang, 2009].

### 1.6 Motivation

The top challenges for ad hoc network design are limited node energy reserves and communication bandwidth. Due to the ad hoc nature of this type of network, network devices are often battery-operated, and thus limited in their energy supply. Bandwidth, on the other hand, is limited by the physical operating frequency of the wireless channel. Cooperative caching protocols for mobile ad hoc networks should try to minimize energy consumption. So far in the literature there is little attention paid to communication overhead occurring in cooperative caching. Most of the cooperative caching schemes developed for MANETs often focus on reducing access latency while ignoring the cost of retrieving the data from neighboring nodes. The major factor that causes message overhead in cooperative caching is cache discovery. Generally, in cooperative caching there are two main approaches for cache lookup: Search based and Directory based. In search based lookup schemes, flooding is the technique used to disseminate data request among the neighboring nodes. For each
local miss, the search message is propagated to all the neighboring nodes
in the network. Although time latency is minimal in flooding, it generates
a large number of messages which will cause excessive control message
overhead as unintended nodes have to receive and process these packets.
As a result, the energy consumption and bandwidth utilization of the
network is increased. Moreover, there is a chance of increased collisions
which could degrade the overall performance of the system. Directory
based technique uses a centralized approach in which a coordinator node
will maintain the status of the data present in the neighboring nodes and
the data requester can get the data directly from the coordinator node.
This approach greatly reduces the number of messages and latency. How-
ever, this approach also imposes several challenges. As the mobile hosts
move freely, maintaining group information is difficult and the control
node may get disconnected which causes excessive overhead.

Another interesting research issue associated with the exiting appro-
aches is network scalability. As the number of mobile clients increases,
the communication overhead between the mobile nodes increases and the
performance is degraded. Against this backdrop, this research work aims
to design an energy efficient and scalable cooperative caching framework.

Because of the limited cache memory available in a mobile device, it
may be necessary to remove some old data in the cache when the cache is
above a certain limit. A cache replacement algorithm that can yield high
hit ratio is necessary for the successful implementation of cooperative
caches. Since the replacement algorithm decides the data to be cached
and removed, it affects the cache hits of future requests. Another factor
that determines the performance of cooperative cache is cache placement.
Among the cooperative caching protocols reported in literature, only a
few have examined cache placement. Uncoordinated cache placement policies can lead to duplication of data. The final motivation for this research is to look into new cache placement and replacement policies that will improve the performance of the cooperative cache.

1.7 Objectives

The main objective of this research work is to develop an efficient cooperative caching framework to improve data accessibility in mobile ad hoc networks. The existing cooperative caching schemes have been studied and an attempt has been made to develop a new cooperative caching technique towards improving data accessibility with minimum energy consumption.

Cache discovery overhead increases with an increase in network size. Design of cache discovery protocols for cooperative caching should consider power and resource limitations of the mobile nodes. Previous studies show that communication is the major source of energy consumption. This emphasizes the need to design a cache discovery scheme that conserves energy. Previous literature says the cache replacement policies play a vital role in improving the cache hit ratio. A cache placement scheme that exploits coordination and sharing of cache state among the neighboring nodes can effectively utilize the cache space available in the cooperative cache.

In order to achieve this, the research work has focused on the following objectives.

- Review the existing cooperative caching schemes proposed for MANETs in order to determine the current state of affairs.
• To propose a novel cache replacement algorithm to improve the cache hit ratio.

• To propose a cache placement policy to store more distinct data items to improve the effective cooperative cache size and thereby increase the cache performance.

• To develop an enhanced cache discovery and data dissemination scheme for cooperative caching which reduces the message overhead consequently leading to lower bandwidth utilization and cost.

• To propose a scalable cache lookup and data discovery framework for cooperative caching in mobile ad hoc networks.

1.8 Contributions of the Research Work

The major contributions of the research work are listed below:

A new improved algorithm is developed for cache replacement which improves performance in terms of cache hit ratio and access latency.

In this work, cache replacement issues for ad hoc networks have been explored and a new cache replacement policy for cooperative caching is presented. The proposed algorithm is an extension of the basic Least Recently Used (LRU) algorithm. The algorithm takes into account the access history of last two references and calculates the inter arrival time of recent references for cache replacement. In LRU only the last time of reference is taken and the number of references is not considered. Since the inter arrival time of the recent reference is taken, more preference
is given to objects that have been accessed more than once. Hence, we are able to distinguish between data that are frequently referenced and the data that are occasionally referenced. The newly developed algorithm takes into account the frequency of access of the data item. This improves the cache hit ratio as well as response time of data access.

**A coordinated cache placement policy to enhance the effective cache size of cooperative cache is proposed.**

In this placement policy, the key idea is to cache as many data items as possible avoiding duplications. Therefore, new coordinated cache data placement algorithm is proposed. The decision on caching an incoming data is done coordinately among the neighboring nodes that already have a copy of the data item. This scheme has been proposed for effective memory utilization for mobile clients with limited memory. Simulation results show that the proposed policy can significantly improve the performance compared to independent cache placement schemes especially for applications with limited cache.

**A distributed cache discovery algorithm which reduces message overhead is presented.**

The objective of the proposed cache discovery process was to minimize the number of messages flooded in the network, which in turn reduces the communication cost and bandwidth utilization. The proposed data discovery process is based on the position of the neighboring nodes. More precisely, message broadcasting is reduced by dividing the transmission range into two zones. This work is extended further to reduce the power consumption by dividing the transmission range in to smaller regions with small set of nodes is each zone. Simulations have been carried out
to find the effectiveness of the proposed models.

A novel virtual backbone based cooperative caching framework is developed to address network scalability.

Existing cooperative caching algorithms for mobile ad hoc networks face serious challenges due to message overhead and scalability issues. To solve these issues, an adaptive virtual backbone based cooperative caching that uses a Connective Dominating Set (CDS) to find the desired location of cached data is proposed. The idea in this scheme is to reduce the number of nodes involved in cache look up process, by constructing a virtual backbone adaptive to the dynamic topology in mobile ad hoc networks. The proposed algorithm is decentralized and the nodes in the CDS perform data dissemination and discovery.

1.9 Outline of the Thesis

Chapter 1 introduces the area of mobile ad hoc networks and cooperative caching.

Chapter 2 is a systematic survey of the existing cooperative caching protocols proposed for mobile ad hoc networks. A brief review of various cache replacement policies available for wireless networks is also presented.

Chapter 3 formulates a scheme for cache replacement. The implementation and performance analysis are also illustrated.

Chapter 4 explains a coordinated cache placement policy. A review of literature on various cache placement techniques is also presented.

Chapter 5 describes the implementation of a distributed cache discovery technique.
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Chapter 6 discusses the various power conservative issues for mobile ad hoc networks. A power conservative design for cache discovery is also presented.

Chapter 7 describes the implementation of an adaptive virtual backbone based cooperative caching framework.

Chapters 8 summarizes the research work, highlights the contributions, and discusses the potential for future research.
1.9. Outline of the Thesis