Chapter 1

Introduction

Recent times have seen a surge of interest in the field of wireless networks. While the lack of wired links gives wireless networks the freedom of mobility of the communicating devices, it also creates some interesting network problems that makes it a challenge to make wireless mobile networks function in reality. Given the current trends, we are fast moving to an era where mobile communication and computing will become ubiquitous. The field of mobile computing is witnessing an exponential growth, both in terms of the number of services provided and the types of enabling technologies that have become available.

A mobile communication network can broadly be categorized as either infrastructure-based or infrastructure-less. The former includes cellular networks and wireless local area networks (WLAN) such as those based on the 802.11 protocol family. Infrastructure-less networks are commonly known as ad hoc networks [2, 42]. There are, of course, the hybrid networks that build ad hoc networks around some rudimentary network infrastructure.

In a cellular mobile network, the network area is partitioned into a number of cells, each of which is serviced by a single base station (BS). The base stations are connected to each other through a wired backbone network, and the mobile terminals or nodes in a specific cell communicate to the base station of that cell through wireless links. A base station allocates
a set of two frequencies to each of the mobile terminals in the cell serviced by it - an uplink channel to talk to the BS and a downlink channel to receive data from the BS. A number of base stations are clustered together and connected to a mobile switching center (MSC). The BSs, MSCs and the inter-connecting wired networks (such as PSTN, ISDN, etc.) form the backbone of the cellular network.

In a cellular environment, a mobile terminal (MT) sends and receives packets only from the base station of the cell it is currently residing in. When a mobile terminal moves from one cell to another, a hand-off of the MT occurs between the old and the new base stations [42,90,148]. In order to send and/or receive data, when a mobile terminal moves from one cell to another, it has to register with the corresponding base station of the new cell. This activity on part of the mobile terminal is coined as location update. On the other hand, when data needs to be delivered to a node, the system can search for the intended receiving node by sending polling signals to the cells close to the last reported location of the node. This process of searching out the location of a node by the system in order to deliver incoming calls is known as terminal paging. The cellular network stores the location information of each mobile terminal in a location database. The database is updated whenever the mobile terminal performs a location update or the system searches out the node through terminal paging. This database update procedure is called location registration [4, 5, 10, 13, 17, 19, 21, 46, 62, 74, 117].

Both paging and location update consume precious system resources like wireless bandwidth and processing power (both at the mobile terminals and at the base station) [95, 96, 113, 122]. Due to bandwidth restrictions, the number of available channels is fixed and limited. If an exhaustive search is performed for each and every call that arrives, the signalling traffic would be enormous even for a moderately large network. This is bound to overload the paging channels rapidly as the call volume grows. However, if the location of each mobile user is known within a limited area, the signalling traffic and paging delay could be minimized to a great extent. Thus, location identification is an important issue in cellular mobile networks.

In an ad hoc network, as opposed to a cellular network, there does not exist any robust com-
munication infrastructure. Ad hoc networks do not have any fixed base station as in a cellular environment. An ad hoc network can be viewed as a distributed system with no central arbiter, consisting of a number of radio transceivers. Such networks are increasingly playing a bigger role in different applications wherever there is either a need for an infrastructure-less communication network or where setting up a wired network infrastructure is not feasible [42]. Examples of such applications include military communications and maneuvers, commercial and residential services such as tracking of vehicle fleet positions by transportation companies, providing location based services to roaming users, emergency search and rescue operations for medical relief, crime control, disaster management, etc. Wireless sensor networks (WSN), that have been steadily gaining attention over the past few years, constitute also another class of ad hoc networks [1, 3, 78]. The sensor devices in WSNs are usually inexpensive, highly energy constrained and with very little computational capabilities. It is normally envisioned that in the near future, sensor networks would consist of hundreds or even thousands of such inexpensive sensors, deployed in the field through scattering (e.g., dropped from air). An example of such a sensor network is the Smart Dust project [134–136]. Sensor devices in WSNs usually have, however, much less mobility.

Mobile ad hoc networks are usually characterized by a single communication channel, relatively short communication link distances compared to cellular networks, dynamic network topology, high bit error rate and battery-energy constrained devices. The dynamism in the network topology arises either due to the mobility of the nodes or due to changes in the channel characteristics that can render a communication link as unavailable, either temporarily or permanently. The high bit error rate is a manifestation of a single communication channel, mobility of the nodes and fluctuations in the channel characteristics.

In a single channel network, all the nodes communicate over a unique common radio frequency, and a message transmitted by a node reaches all its neighbors (nodes that are within its transmission zone) in the same time step. If two or more nodes start transmitting simultaneously, the individual messages are garbled beyond recognition, and this phenomenon is
termed as a collision. Collisions lead to retransmissions which result in drain on battery power of the nodes and increase in message delivery latency. A node is said to possess collision detection capability if it can distinguish between such garbled messages and the channel state with no signal. The nodes may or may not possess such collision detection capability. When the nodes do not have collision detection capabilities, communication protocols are so developed as to avoid the occurrence of such collisions. In the other case, collisions are detected and then resolved by appropriate protocols.

As in the cellular networks, location identification in ad hoc networks is an important issue in properly rendering the various types of military and civilian services (e.g., medical relief, disaster management, rescue, etc.). Furthermore, in wireless sensor networks, the performance of WSNs is crucially influenced by how accurately the sensor nodes within the network are localized. Sensor localization information is used in self-organization and configuration of the networks, in deciding the origin of events and tracking moving targets, and so on. However, often errors are introduced in such location estimation system due to non line-of-sight (NLOS) propagation of signals arising out of scattering and reflection. The Global Positioning System (GPS) [73, 109] is perhaps the most widely publicized location-sensing system. Unfortunately, GPS does not scale well in dense urban areas or in indoor locations. Several authors have attempted to mitigate the effect of NLOS errors by suitable models. While reasonably accurate radio propagation models exist for outdoor conditions [51, 52, 65], there are no such unanimously accepted models for indoor environments [8, 11, 28, 40, 108, 137, 143]. Due to the lack of proper models, location estimation in all the existing techniques are either very time-consuming or contains large errors so that the node may be far away from the estimated point.

In view of the rapidly increasing number of mobile users all over the world, allocation of communication channels to the mobile users in both cellular and ad hoc environments have become an extremely important issue [90]. In the cellular environment, the available frequency band is predetermined and limited, while for the ad hoc environment, this problem
is all the more serious due to the (usually) single frequency band used by all the mobile terminals. Although there are many existing communication protocols for avoiding collision in the ad hoc environment, [15], [36], [38], [37], [31], [14], [87], the existing protocols for slot assignment to the individual mobile terminals are too conservative, and may not be efficient enough to handle the channel demand in large networks.

Another critical aspect of mobile networks is the constraint on the battery energy of the nodes. Given the typical application scenarios of such networks and the mobility of the nodes, it is not feasible to recharge or replace the batteries of the devices frequently. Given the fact that in most modern day devices used in mobile networks, communication usually requires more energy expenditure than computations, this leads to the problem of designing energy efficient communication protocols that can provide a longer battery life to the nodes. Most current research efforts on reducing energy consumption have focussed on the MAC layer design [48, 63, 64, 132], optimizing data transmissions by reducing collisions and retransmissions [15, 25, 29, 55, 94, 125] and through intelligent selection of paths or special architectures for sending data [50, 72, 77]. In all such schemes, the underlying communication strategy of sending a string of binary bits is energy based transmissions (EbT) [30, 151], which implies that the communication of any information between two nodes involves the expenditure of energy for the transmission of data bits. A new communication strategy called Communication through Silence (CtS) have been proposed in [30, 151] where authors considered silent periods as opposed to energy based transmissions. CtS suffers from the disadvantage of being exponential in time. It introduces long delays and adversely affects the network throughput. There is also the problem of maintaining synchronization between sender and receiver over long periods of silence.
1.1 Scope of the Thesis

In this thesis, we address the problems of location identification in both cellular and ad hoc networks, allocation of communication time slots for avoiding collisions in ad hoc networks, broadcast and gossiping in ad hoc networks, and finally energy efficient communication protocols in wireless networks.

1.1.1 Location Identification

For the location identification problem, we first critically analyze the errors in range measurements (arising from both line-of-sight (LOS) and NLOS signals) as well as in the positional estimate of each node, and then devise a suitable algorithm for finding a better estimate about the location of a node.

Next, rather than doing a location prediction with some error estimates, we consider the location discovery problem in terms of finding the minimum region of residence where a node is guaranteed to be found. Using computational geometric methods, we show that with the help of a few reference nodes in the network (whose initial regions of residence are known), we can compute the region of residence of every non-reference node such that, the size of the region of residence of every node in the network is minimized.

1.1.2 Communication Issues

We next address the communication issues in ad hoc networks. First we consider the allocation of time slots in an ad hoc network for avoiding collisions among different nodes so that time slots can be properly re-used among the sufficiently distant nodes in the network. Theoretical lower bound on the required number of slots has been derived, followed by an optimal slot assignment algorithm.
We then present deterministic broadcast and gossiping algorithms for mobile ad hoc networks with low broadcast latency, assuming the presence of collision detection capabilities at the mobile terminals. The deterministic broadcast algorithm is based on breadth-first traversal of the nodes of the network and works efficiently for scenarios where network topologies change frequently due to high mobility of the nodes. The idea of broadcasting is then extended to develop an efficient deterministic gossiping algorithm.

Finally, we propose a communication technique that first recodes a binary coded data using a redundant radix based number representation [128] and then uses silent periods to communicate the bit value of '0'. Theoretical results on average energy savings are derived. We also develop a benchmark test suite called the energy efficient communication (EEC) benchmark suite, in order to judge the performance of the energy efficient communication strategies. Experimental results show that our proposed transmission protocol achieves on an average, an increase of nearly 69% in energy savings, when compared to existing energy based transmission schemes, without any degradation in the network throughput.

1.2 Organization of the Thesis

A review of works related to the problems addressed in this thesis has been presented in chapter 2.

Chapter 3 deals with the analysis of errors in location estimation using the method of triangulation or trilateration, followed by describing an algorithm for minimizing this error.

In chapter 4, we present a technique, based on computational geometry, for identifying the region of residence of a mobile node within which it is guaranteed to be found.

Next, in chapter 5, using the location information of a node, we first derive a tight lower bound on the number of slots needed for collision-free communication in ad hoc networks, and then propose an optimal algorithm for allocating the time slots to different nodes.
In chapter 6, we present the broadcast and gossiping algorithms for ad hoc networks assuming that the mobile terminals have collision detection capabilities.

Chapter 7 deals with the energy efficient communication in wireless networks, followed by conclusion in chapter 8.