CHAPTER 1

BACKGROUND

1.1 Wireless Networks

Wireless communication is one of the fastest growing industries in the world. Wireless communications often provide the last mile connectivity for networks, communicating devices, military applications, radios, mobile networks like CDMA and GSM, and other stationary or mobile field equipment. It has many advantages compared to wired networks. Some of the advantages are instantaneous and flexible network setup, easy deployment of network in areas where computer installation of permanent infrastructure of computer communications is difficult or too expensive.

Wireless communication is categorized into several segments such as satellite-based, cellular telephony, wireless LAN communication network etc. These segments are classified into infrastructure dependent and infrastructure independent. Cellular networks as shown in Figure 1.1 are infrastructure dependent networks. In cellular networks, a call between two nodes is completed through the base station. These are termed as single-hop wireless Networks.

Adhoc wireless networks are capable of operating without any fixed infrastructure support. The routing takes place in a distributed manner in which all nodes cooperate with each other for efficient communication as shown in Figure 1.2. Mobile nodes in Ad Hoc networks are more complex than cellular nodes. In adhoc networks, mobile nodes take intelligent decisions at the time of communication, as a network host for transmitting / receiving data and as a network router for routing packets from other nodes. Routing and resource management in cellular networks are simple. However, such networks may not be feasible in certain cases, due to economic reasons i.e. the cost associated with installing antennas, switches for call forwarding, location registers to find a mobile station and the fee associated while buying the electromagnetic spectrum by the customers. This makes the whole system expensive [1, 2].
There are applications, which need a decentralized wireless network, minimal configuration and quick deployment. These kinds of networks are suitable for emergencies like natural disasters, military applications, and temporary video conferences etc.

Fig 1.1 Cellular networks

Fig 1.2 Adhoc Wireless Networks
The adhoc network deployed on fly, in which even if a user moves away from the network coverage area, still have communication far beyond the range. Communication takes place between users by relaying through many intermediate nodes. Thus, they are called multi-hop wireless networks. This can be accomplished by allowing each node to act as a source node or an intermediate node, which can forward data packets to other nodes. This is achieved dynamically based on the network connectivity. Such networks are called Adhoc Wireless Networks (AWN) [3, 4].

1.2 Adhoc Wireless Networks

Adhoc Wireless Networks are broadly categorized into three types

- Mobile Adhoc Networks (MANETs)
- Wireless mesh networks
- Wireless sensor networks

1.2.1 Mobile Adhoc Networks (MANETs)

MANET is a set of mobile agents, which communicate with one another within radio frequency range. They do not rely on any infrastructure and operate in a decentralized manner. This kind of network is suitable in situations like battlefields and major rescue operations. Since the communication traffic has to be relayed over several intermediate nodes, MANETs are also known as Multi Hop ad hoc networks. The nodes not only perform as hosts, but also as routers to forward packets to other nodes.

1.2.2 Wireless sensor networks and wireless mesh networks

MANET is considered a special case for wireless mesh network and wireless sensor network. However, there are few differences in their usage,

- **Wireless Sensor networks** – sensor networks have low mobility and the size of the network can vary based on application, which is usually high as compared to MANET.

- **Wireless mesh networks** - many mesh networks are not mobile and do not support mobility.
1.3 Major challenges of MANETs

While MANETs have several advantages, they face a few major challenges.

- **Error prone-shared wireless channel**: The wireless channel is a broadcast medium in nature and hence is prone to errors due to several impairments such as shadowing, thermal noise, and multipath propagation and fading. This makes it challenging for MANETs to provide efficient packet delivery ratio as well as link connection guarantee.

- **Dynamic Topology due to node mobility**: The nodes do not have any restrictions on mobility and hence can move randomly and independently. Due to this there may be frequent path breaks affecting the QoS session, there by requiring QoS sessions to be re-established. This re-establishment of QoS session in the form of updating routing table and finding an alternate path may cause some delay which may not be acceptable in applications where the targets/deadlines cannot be missed.

- **Decentralised Control**: MANETs are created on the fly and do not have central co-ordinators to coordinate the activity of nodes. Communication takes place in a decentralised manner with the help of locally-available state. This complicates QoS provisioning in MANETs due to algorithms overhead and complexity.

- **Channel Contention**: Nodes in MANETs communicate on a common channel which causes problems like interference and channel contention. Nodes which are not in the same range but which have a common node send a request packet. Common node which receives data from two different nodes will have packet collision causing hidden terminal problem. These collisions further waste channel capacity as well as battery power and further increase delay which will leads to packet drops.
• **Limited Device Availability**: Computational power, storage space, and battery life are critical resources in MANETs which significantly affects the performance of MANETs while providing QoS. Less memory limits the storage of QoS state leading to more frequent updations. Battery power will drain fast due to control packets which are used to find the destination, return error etc. Hence, efficient device management mechanisms are required for optimal utilisation of these scarce resources [5, 6].

### 1.4 Routing in MANETs

Nodes in MANETs are highly dynamic in nature. Due to this, routing in MANETs will become one of the most significant challenges. As a result, an efficient routing protocol has to be developed which is capable of reducing control overhead and utilizes the bandwidth efficiently.

Major research work in developing efficient routing algorithms has resulted in development of multiple routing algorithms. These algorithms are categorized as:

- Table driven protocol
- On Demand protocol
- Hybrid protocol

**Table driven protocol**: These protocols maintain information of network topology in the form of routing tables. Routing tables are flooded into the whole network, so that every node has the routing information. Since the information is already present and active on all nodes, these are called proactive routing protocols. If data has to be transmitted from source to the destination then nodes run a path-finding algorithm on the topology information it maintains in the form of the routing table. Route maintenance is through periodic information exchange. This kind of network is suitable for wired networks and gives accurate network state information while transmitting data.
On Demand protocol: This is also known as reactive routing protocol. This does not maintain information of the network topology. When a node wants to transmit data to a destination, it requests on demand its neighboring nodes to give destination address details. This request propagates until the address of the destination is found or the destination itself is found. After finding many paths to the destination, it finds the best path in terms of less hop count or less delay and transmits data to the next intermediate node. A node executes the path finding process and exchanges information only when a path to the destination is required. This kind of network is suitable for wireless networks and is used in applications of MANETs.

Hybrid protocol: Makes use of the best features of Table driven protocols and On demand protocols. Hybrid protocols divide the network into zones. If a destination is within the zone Table Driven, approach is adopted else, if the destination is outside the zone then on-demand approach is adopted [1, 7].

1.5 Quality of Service

Despite lot of research on MANETs, there are many challenges as far as real time applications are concerned. Hence, the focus is shifting to providing higher and better Quality of Service (QoS) or best effort services. QoS is the level of service provided by the network to the requesting user. By providing QoS the network behaves in a deterministic way, so that the information can be delivered in an efficient manner and the resources can be utilised efficiently. QoS can be provided by a network in different forms, the requirements vary from one application to the other. A service can be characterised by a set of measurable requirements such as efficient packet delivery ratio, minimum bandwidth, delay, availability etc.

The network after accepting the user requirement has to ensure that the service requested by the user is met. It has to ensure that the packet should reach the destination without any obstacles. This is done by finding a path where there are no loops. It will also make sure that the necessary resources are available to the service requirements for providing QoS. The process of finding a path with QoS guarantee is known as QoS routing. After finding a path, with proper resource reservation techniques resources are reserved for QoS guarantees.
One such application is as shown in Figure 1.3 where a multimedia file has to transmit within 100s delay. This is achieved by route discovery phase in which it checks that the delay of route request packet to the destination is within 100 secs. The reply packet also makes sure that the path selected for a data packet is within the user requirement. Once the requirement of the user is met then the transmission of the packet takes place between the source and the destination.

**1.5.1 QoS parameters in ad hoc wireless networks**

Service requirements as well as QoS parameters vary from application to application.

- Multimedia Applications- delay, delay jitter and bandwidth
- Military applications - Secured routing
- Emergency search in case of natural calamities – Availability of the node
- Group communication – Battery life

In MANETs, the service requirements are influenced by resource constraints of nodes such as battery charge, memory and processing power etc [8, 9].

![Figure 1.3 QoS in MANETS with Delay as a parameter](image)

**1.5.1 Different QoS methodologies for MANETs**

Following are some methodologies used in MANETs for providing QoS.

- Controlled node movement
- Clustering
- Vertical coupling (cross layer interactions)
- QOS adaptation

**Controlled node movement**
QoS is provided in MANETs using control node movement in which a topology control algorithm is used which adapts mobility model for the movement. Unlike other protocols in MANETs, where the routing table changes every now and then, in this technique the connectivity of the network is maintained throughout and hence there is no need to change the routing table. Every node being autonomous, travels with its own velocity and changes it to maintain the connectivity with the target node. This is accomplished with the help of Global Positioning System (GPS) and the transceiver installed on all the nodes. This technique demonstrates that the connectivity is always maintained and hence the topology.

**Clustering**
As the nodes in MANETs increase in terms of thousands, maintaining a routing table is a major problem. This is due to the resource constraint (memory) in MANET which also leads to route maintenance problems, looping of packets and load balancing problem etc. To avoid these problems MANETs divides itself into clusters. These clusters will form a hierarchy by electing a cluster head among them. Collection of all cluster forms a super cluster. The cluster head knows information about the nodes within the cluster. A Super cluster head will know information about other cluster heads. Each node has one hop link information required to forward information on the route to its cluster head. This eliminates overhead in MANETs which is generally caused due to control packets (used for route discovery, route maintenance etc.).

**Vertical coupling (cross layer interactions)**
In contemporary network architecture, multilayered concept is used in which different layers act independently without affecting the performance of the other layers. This is a standard paradigm used in traditional networking; however, this does not lead to optimal performance in MANETs for providing QoS. Cross-layered designs share information across the layers and will help to improve
network performance by exchanging inherent layer information and fine-tune their parameters according to the network status as shown in Figure 1.4. This will minimize the errors while receiving and transmitting multimedia files and take necessary decisions to act dynamically over layers with different parameters.

- **QoS adaptation**
  A better network should adapt QoS in a dynamic manner. This is accomplished in MANETs. It has protocols, which adapt to the network conditions at all times and may be able to produce better performance as compared to conventional network protocols that have static behavior. Conventional Networks have a fixed set of actions at all times, irrespective of the network conditions [10].

![Cross Layer Architecture](attachment:image.png)

**Fig 1.4 Cross Layer Architecture**

### 1.6 Social insects and stigmergy

Biological insects like ants, termites and bees are known to have a complex social structure. Swarm Intelligence (SI) is one such emergent property of these social insects that shows a ubiquitous character called stigmergy. Grasse et al defined the
term stigmergy in their research on the construction of termite nest. Pierre-Paul introduced the stigmergy in the late 1950’s. Stigmergy is defined as a means of communication via signs placed in the environment [11].

Figure 1.5 shows a schematic diagram of a termite nest, which is several meters high, constructed largely from mud pebbles and from the saliva of termite workers. It is quite surprising to see cognitive capability of a single termite that can build such a complex structure. These insects independently and collectively exhibit problem-solving abilities. This cooperation is distributed among the entire population, without any centralized control. Each individual follows a set of rules that is influenced by locally available information. This emergent behavior helps these insects to solve any complex problem. Additional properties that swarm intelligent systems possess include robustness against individual misbehavior or loss, the flexibility to change quickly in a dynamic environment, and an inherent parallelism or distributed action [12].

Grass et al [11] showed that coordination and regulation of the termite nest building activity did not depend on the workers themselves, but was achieved by some kind of stimulating configuration of materials that triggered a response in a termite. However, to date nobody could understand how the specific trigger-response configuration and stimuli must be organized in time and space to allow appropriate co-ordination. Inspite of these ambiguities stigmergy is recognized as the best concept to understand the evolution and maintenance of social behavior of insects. It is also becoming popular in other fields such as artificial intelligence, robotics, political and economic sciences.

![Fig 1.5 Schematic diagram of termite nest](image)
Another excellent case of stigmergy in nature is deposition of pheromone by ants in food foraging process. All the individual ants deposit a chemical substance called “Pheromone”. This chemical helps other foragers to follow the trails and reinforce those trails by dropping more pheromone. This process helps in selecting the shortest path from the nest to a food source. This scenario is shown in Figure 1.6, where an ant travels randomly in search of food. The next group of ants tries to follow the trail based on the pheromone concentration available on that path. Higher the concentration the more they are attracted towards the path. If there is an obstacle in between, they chose random path and move forward until another trace of pheromone is found.

![Figure 1.6](image)

**Fig 1.6** Food foraging behavior in ants [13]

### 1.7 Swarm Intelligence

Swarm Intelligence (SI) is the intelligence shown by biological insects such as ants, termites, wasps and bees. These insects independently and collectively exhibit problem-solving abilities. Each individual follows a set of rules that is influenced by locally available information. This cooperation is distributed among the entire population, without any centralized control [13, 14].
Based on the routing pattern followed in the swarm intelligence, multiple routing algorithms are identified. Following is the list of general principles in SI routing algorithms.

- Repeated Path Sampling
- Stochastic Pheromone-based Decisions
- Multiple Data Paths

- **Repeated path sampling:** As compared to traditional distance vector approach, (routing information is calculated based on update messages received from nodes or links) SI routing algorithms gather information through repeated sampling. This real information from multiple ants, which are mutually redundant, avoids the creation of errors in the network.

- **Stochastic pheromone-based decisions:** Indirect communication, among ants in food foraging by sensing a pheromone trail laid by previous ants is stated as “stigmergy”. Ants, exploring multiple paths to reach a food source in a stochastic manner help SI algorithms to be adaptive and handle load efficiently.

- **Multiple data paths:** To handle resources in a network efficiently, an ant carries a pheromone table, which is constructed when it traverses from a given source to the destination. A pheromone table can have multiple paths to the destination. Whenever there is failure on the optimal path decided by the ant, it checks for the next best entry in the pheromone table and follows the path [15].

A typical swarm intelligence system has the following properties:

- It is composed of many individuals called “Agents”
- Individuals are homogeneous
- Agents exploit only local information in the form of “Pheromone” found in the environment and interact with each other indirectly
• Overall behavior of the system results from interactions of the individuals with each other and with their environment

1.8 Basic Principle of Swarm Intelligence

Ants that are in search of food inspite of a highly changing environment are able to self-organize based on following four principles.

• Positive Feedback
• Negative Feedback
• Randomness
• Multiple interactions

❖ **Positive feedback:** This improves good solutions by laying more pheromone as more ants travel on that path and tells other ants that it could be the best path to reach the destination.

❖ **Negative feedback:** This mechanism helps to destroy bad solutions by decaying the pheromone with respect to time. However tuning of pheromone decay is problem specific i.e. good solutions should not be lost fast and bad solutions are evaporated fast.

❖ **Randomness:** Path chosen by ants is completely random; hence, there is a possibility of generation of new solutions.

❖ **Multiple interactions:** In the food searching process, food can be found faster if more ants interact. Otherwise, with just one ant, the pheromone decays fast and hence many ants are needed to sustain a good solution [14] [15] [16].

1.9 Swarm Intelligent framework

The attraction of ants to pheromone signifies the positive feedback in swarm intelligent systems. A stronger pheromone trail is built on the shorter path, and this allows ants to avoid any suboptimal solution. As more ants are attracted to the shorter path with the stronger pheromone trail, its intensity grows even stronger, thereby attracting even more ants.
Contrary to pheromone deposition, pheromone evaporation limits the amount of pheromone that can be placed on a trail. This helps ants to avoid paths, in which obstacles were found.

As shown in Figure 1.6 there are equal ants on both routes around an obstacle, however the longer path was not chosen because the ants cannot possibly put enough pheromone on it fast enough to overcome the bias of the shorter path. This effect is due to a combination of the pheromone decay rate and the number of ants on that trail. Thus, pheromone decay represents negative feedback. Stale solutions are slowly removed from the system. The number of ants in food foraging behavior plays a major role.

If there are fewer ants, then the probability of leading to a food source will be less, since the pheromone deposition will be less. This leads to a situation in which by the time ant reaches the trail, the pheromone concentration would have evaporated. Hence, many ants are required to test available paths to a food source. In process, experience by each ant varies hence; it must be averaged out over time.

Ants communicate indirectly through pheromone laid on the ground. Necessary information required to solve the shortest/optimal path problem is available in the pheromone. Eventually, the act of choosing a path based on stronger pheromone value yields the emergent shortest path. This also helps ants to adapt to a new environment [17,18].

1.10 Applications of Ant Colony Approach for networks

Nodes in an ad hoc network can directly communicate with another node located within their radio transmission range. A highly reliable ad hoc network protocol is a must for the network wherein nodes are constantly changing their location and some may be moving out of the communication range of each other. The major challenges of such networks are scalability, mobility, security, bandwidth availability and power backup of nodes. Bluetronix has solved these issues with their intelligent distributed algorithms [19].
The biological ants in an ant colony can be compared to artificial agents in MANETs. Here each agent builds a solution by using problem specific information and the information added by agents during previous iterations. This indeed helps agents to modify the representation of the problem in such a way that information contained in the past can be exploited to build better solutions. The core concept of an ant colony paradigm is retained and applied in datagram networks (wireless) to solve routing problems, since the structure, the dynamicity and the optimization issues in ant colony are comparable with the issues faced in MANETs.

**Comparative characteristics of ant colony algorithm as applied to MANETs.**

- At each network node, mobile agents (packets with autonomous behavior, intelligent decision making capability and mobile in nature) are asynchronously launched towards a randomly selected destination node (at regular intervals).

- These Autonomous agents act concurrently and communicate indirectly through the information gathered in the form of pheromone concentration (in routing table) and search for the minimum cost path between the source and destination.

- In this process, each agent moves systematically and at each intermediate node adopts a greedy stochastic policy (e.g. time length, congestion status etc...) to choose the next node to reach the destination.

- Once they reach the destination, the agents (acknowledgement packets) follow the same path in the reverse order to reach their source node. In this process network, status and local pheromone concentration (routing tables) are also modified at each intermediate node.

- The agents die once they reach the source node.

**Extra features adopted by artificial ants for routing in networks are as follows**

- Transition of ants is in discrete states
- Carries internal state which contains memory of past action
• Deposits an amount of pheromone which is a function of the quality of the solution found
• Pheromone laying and decaying of artificial ants are problem dependent and do not reflect real ants
• Local optimization can be added to improve the system efficiency

By following above features, Ant algorithm with a finite size of artificial ants search for good solutions to the optimization problems. Quality solutions are found through global cooperation among all the agents of the colony trying to build different solutions.

Advantages of Swarm Intelligence (SI) in Networks

• **Multipath routing** – It is possible to generate multiple paths between a pair of nodes.

• **Efficient route discovery** – If optimal path fails, then packets can easily be sent to other neighbors by re-computing next hop probability.

• **Fault Tolerant and Distributed** - SI algorithms are inherently distributed with no centralized control mechanism. Even if a node or link fails, there will not be any heavy loss.

• **Scalable** – Population of ants are network size specific. The agents may die or reproduce without affecting the performance of the network.

• **High Speed** - Change in the network is adopted very fast without degrading the performance [20].

1.11 Major categories of SI algorithms

Mainly, there are two important concepts in Swarm Intelligence (SI). They are Ant Colony Optimization (ACO) (inspired by ant species food foraging behavior) and Particle Swarm Optimization (PSO) (Inspired by flocking of birds and school of fishing).
1.11.1 Ant Colony Optimization (ACO)

ACO has inspired multiple algorithms and one such algorithm is Ant System (AS). An ant system chooses the best path laid by a previous ant, which went in search of food and has returned. ACO deals with artificial systems, which are inspired by food foraging behavior of real ants, which can find optimal solutions inspite of the changes in the environment. The main concept is indirect communication between the ants by means of pheromone trails, which helps them to find the shortest path between their nest and food. ACO is currently applied to applications, such as graph coloring problems, scheduling problems, traveling sales man problem, network routing problem, clustering, robotics etc.

Some important properties of MANETs are observed after the application of ACO. These observations will illustrate how SI algorithms could perform well in MANET.

- **Dynamic Topology** - Due to mobility, the topology of the network changes very frequently. The performance degrades due to dynamic topology. ACO is an agent-based system, which can adapt to the dynamic nature of the network.

- **Local Work** – Ants communicate based on locally available information in the form of pheromone trails. This feature will help MANETs to utilize resources like bandwidth, batter power etc efficiently.

- **Link Quality** – The decision of the best path can be integrated based on pheromone concentration and quality of the link. The nodes will have authority to change the pheromone concentration, which is independent of ants.

- **Support for multipath** - ACO supports multipath by laying pheromone to reach the destination on different paths. This pheromone with the highest concentration helps a data packet in MANETs to travel on the shortest
path. Even if there is a failure in the network, the data packet will select the next best pheromone concentration in the pheromone table.

1.11.2 Particle Swarm Optimization (PSO)

PSO is an important category of SI algorithms for optimization problems. It is inspired by social behavior found in birds and fish. PSO is a population based stochastic optimization technique that is initialized with random solutions and searches for optima by updating generations. The solutions in PSO are called “particles”. A particle flies through the problem space, keeps track of its coordinates in the problem space by changing the velocity of each particle, and finds the best solution it has achieved so far called ‘pbest’. The location of the ‘pbest ‘is called ‘lbest’. This location helps in getting the best value called ‘gbest’.PSO is attractive as it needs fewer parameters to adjust and hence is faster and cheaper as compared to other methodologies [21].

1.12 Types of Swarm Intelligence based ACO algorithms for routing

There are different types of SI algorithms, which are used for routing in networks.

- **Ant Based Control (ABC) algorithm** was the first routing algorithm for circuit switched networks in the year 1996. It used mobile agents for generation of route to the destination. As they move in search of a destination, they lay artificial pheromone. This artificial pheromone is a function of distance from source to current node. The next hop is selected based on the pheromone values stored in the form of pheromone table for all possible destinations in each node. These pheromone values are probabilities, which help the ant to select the best one to reach the destination.

- **Ant Net (AN)** design is based on Ant colony optimization (ACO) that was introduced for packet switched networks. It is a swarm intelligence algorithm for the adaptive best effort routing in IP networks that defines a nature inspired meta
heuristic for optimization problems. In this algorithm, the shortest path is the one with fewer hops. This works in two phases - forward phase and backward phase. During forward phase, each ant constructs a path from source to destination with the help of local information and indirect communication by sensing the pheromone. After reaching the destination, the backward ant starts in the reverse order where it evaluates the followed path with respect to destination and updates routing information.

- **Ant Colony Based Routing Algorithm (ARA)** was used for routing in MANET. This algorithm not only generates route between nodes but also maintains the routes. Hence, the algorithm is divided into three main functions namely route discovery, route maintenance and route failure.

- **Mobile Ant Based Routing (MABR)** Another SI algorithm suitable for MANET and is based on Antnet algorithm. This uses three protocols for routing as listed below
  - Topology Abstracting Protocol (TAP)
  - Mobile Ants – Based Routing (MABR)
  - Straight Packet Forwarding (SPF)

TAP generates a simplified network based on logical links and routes in which a single routing table may be distributed for nodes, which are part of a logical router. MABR is used for routing on the logical topology provided by TAP in which AntNet like protocol is applied. Here both forward and backward ants are used to find the destination address and parallely the logical link probabilities are updated. SPF finally transfers the data of the simplified topology between the logical routers [15, 16, and 17] [22, 23, and 24].