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An Efficient Shortest-Path Aided Back-Pressure Routing over Multihop Wireless Network

T. Antony Thobias, P. Vijayananth, S. Manikandan

Abstract—This project proposes a new optimal routing/scheduling back-pressure algorithm that not only guarantees network stability (throughput optimality), but also adaptively selects a set of optimal routes based on shortest-path information in order to minimize average path lengths between each source and destination pair. Our results indicate that under the traditional back-pressure algorithm, the end-to-end packet delay first decreases and then increases as a function of the network load (arrival rate). The proposed particle swarm optimization based back pressure algorithm adaptively selects a set of routes according to the traffic load and energy efficiency so that long paths are used only when necessary, thus resulting in much smaller end-to-end packet delays as compared to the traditional back-pressure algorithm.

Index Terms – Back-pressure, PSO Algorithm, Multihop, Throughput Optimal

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1 Introduction

Due to the scarcity of wireless bandwidth resources, it is important to efficiently utilize resource to support high throughput, high-quality communications over multihop wireless networks. In this context, good routing and scheduling algorithms are needed to dynamically allocate wireless resources to maximize the network throughput region. To address this throughput-optimal routing and scheduling, first developed in the seminal work, has been extensively studied. While these algorithms maximize the network throughput region, additional issues need to be considered for practical deployment. With the significant increase of real-time traffic, end-to-end delay becomes very important in network algorithm design. The traditional back-pressure algorithm stabilizes the network by exploiting all possible paths between source–destination pairs (thus load balancing over the entire network). While this might be needed in a heavily loaded network, this seems unnecessary in a light or moderate load regime. Exploring all paths is in fact detrimental-it leads to packets traversing excessively long paths between sources and destinations, leading to large end-to-end packet delays.

Back-pressure-type algorithms have recently received much attention for jointly routing and scheduling over multihop wireless networks. Good routing and scheduling algorithms are needed to dynamically allocate wireless resources to maximize the network throughput region. While this extensive exploration is essential in order to maintain stability when the network is heavily loaded, under light or moderate loads, packets may be sent over unnecessarily long routes, and the algorithm could be very inefficient in terms of end-to-end delay and routing convergence times. This project presents a routing/scheduling back-pressure algorithm that not only guarantees network stability (throughput optimality), but also adaptively selects a set of optimal routes based on shortest-path information in order to minimize average path lengths between each source and destination pair. The disadvantages of this system are End to end delay, routing convergence time.

Wireless access points are also often close to humans, but the drop off in power over distance is fast, following the inverse-square law. The HPA's position is that "...radio frequency (RF) exposures from WiFi are likely to be lower than those from mobile phones." It also saw "...no reason why schools and others should not use WiFi equipment." In October 2007, the HPA launched a new "systematic" study into the effects of WiFi networks on behalf of the UK government, in order to calm fears that had appeared in the media in a recent period up to that time". Dr Michael Clark, of the HPA, says published research on mobile phones and masts does not add up to an indictment of WiFi

2 Wireless Network

Wireless network refers to any type of computer network that is not connected by cables of any kind. It is a method by which homes, telecommunications networks and enterprise (business) installations avoid the costly process of introducing cables into a building, or as a connection between various equipment locations. Wireless telecommunications networks are generally implemented and administered using a transmission system called radio waves. This implementation takes place at the physical level (layer) of the network structure.

The term refers to any kind of networking that does not involve cables. It is a technique that helps entrepreneurs and telecommunications networks to save the cost of cables for networking in specific premises in their installations. The transmission system is usually implemented and administrated via radio waves where the implementation takes place at physical level. The types of networks are defined on the bases of their size (that is the number of machines), their range and the speed of data transfer.

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Wireless PAN - Personal area network Wireless Personal Area Networks. Such networks interconnect devices in small premises usually within the reach of a person for example invisible infra-red light and Bluetooth radio interconnects a headphone to a laptop by the virtue of WPAN. With the installation of Wi-Fi into customer electronic devices the Wi-Fi PANs are commonly encountered.

Wireless LAN - Local Area Network The simplest wireless distribution method that is used for interlinking two or more devices providing a connection to wider internet through an access point. OFDM or spread-spectrum technologies give clients freedom to move within a local coverage area while remaining connected to the LAN. LAN's data transfer speed is typically 10 Mbps for Ethernet and 1 Gbps for Gigabit Ethernet. Such networks could accommodate as many as hundred or even one thousand users.

Wireless MAN - Metropolitan Area Networks, The wireless network that is used to connect at high speed multiple wireless LANs that are geographically close (situates anywhere in a few dozen kilometers). The network allows two or more nodes to communicate with each other as if they belong to the same LAN. The set up makes use of routers or switches for connecting with high-speed links such as fiber optic cables. WiMAX described as 802.16 standard by the IEEE is a type of WMAN.

Wireless WAN is the wireless network that usually covers large outdoor areas. The speed on such network depends on the cost of connection that increases with increasing distance. The technology could be used for interconnecting the branch offices of a business or public internet access system. Developed on 2.4GHz band these systems usually contain access points, base station gateways and wireless bridging relays. Their connectivity with renewable source of energy makes them stand alone systems. The most commonly available WAN is internet. Mobile devices networks the advent of smart phones have added a new dimension in telecommunications; today's telephones are not meant to converse only but to carry data.

GSM - Global System for Mobile Communications Global System for Mobile Communications is categorized as the base station system, the operation and support system and the switching system. The mobile phone is initially connected to the base system station that establishes a connection with the operation and support station that later on connects to the switching station where the call is made to the specific user.

PCS - Personal Communications Service is a radio band that is employed in South Asia and North America; the first PCS service was triggered by Sprint. D-AMPS Digital Advanced Mobile Phone Service is the upgraded version of AMPS that is faded away due to technological advancements. TAN - Tiny Area Network and CANs - Campus Area Networks are two other types of networks. TAN is similar to LAN but comparatively smaller (two to three machines) where CAN resemble MAN (with limited bandwidth between each LAN network).

The Utility of Wireless Networks the development of wireless networks is still in progress as the usage is rapidly growing. Personal communications are made easy with the advent of cell phones where radio satellites are used for networking between continents. Whether small or big, businesses uses wireless networks for fast data sharing with economical means. Sometimes compatibility issues with new devices might arise in these extremely vulnerable networks but the technology has made the uploading and the downloading of huge data a piece of cake with least maintenance cost.

3 MULTI-HOP NETWORKING

Multi-hop or ad hoc, wireless networks use two or more wireless hops to convey information from a source to a destination. There are two distinct applications of multi-hop communication, with common features, but different applications.

Mobile ad hoc networks (MANETS) A mobile ad hoc network consists of a group of mobile nodes that communicate without requiring a fixed wireless infrastructure. In contrast to conventional cellular systems, there is no master-slave relationship between nodes such as Òbase station to mobile usersÓ in ad hoc networks. Communication between nodes is performed by direct connection or through multiple hop relays. Mobile ad hoc networks have several practical applications including battlefield communication, emergency first response, and public safety systems. Despite extensive research in networking, many challenges remain in the study of mobile ad hoc networks including development of multiple access protocols that exploit advanced physical layer technologies like MIMO, OFDM, and interference cancellation, analysis of the fundamental limits of mobile ad hoc network capacity, practical characterization of achievable throughputs taking into account network overheads.

Multi-hop cellular networks Cellular systems conventionally employ single hops between mobile units and the base station. As cellular systems evolve from voice centric to data centric communication, edge-of-cell throughput is becoming a significant concern. This problem is accentuated in systems with higher carrier frequencies (more path loss) and larger bandwidth (larger noise power). A promising solution to the problem of improving coverage and throughput is the use of relays. Several different relay technologies are under intensive investigation including fixed, mobile relays (other users opportunistically agree to relay each other's' packets), as well as mobile fixed relays (fixed relays that are mounted on buses or trains and thus moving). There has been extensive research on multi-hop cellular networks the last few years under the guise of relay networks or cooperative diversity. The use of relays, though, impacts almost every aspect of cellular system design and optimization including: scheduling, handoff, adaptive modulation, ARQ, and interference management. These topics are under intense investigation.

4 Multi-Hop Wireless Sensor Networks

In multi-hop wireless networks, communication between two end nodes is carried out through a number of intermediate nodes whose function is to relay information from one point to another. There are two distinct applications of multi-hop communication, with common features, but different applications.

Cellular systems conventionally employ single hops between mobile units and the base station. As cellular systems evolve from voice centric to data centric communication, edge-of-cell throughput is becoming a significant concern. This problem is accentuated in systems with higher carrier frequencies and larger bandwidth. A promising solution to the problem of improving coverage and throughput is the use of relays. Several different relay technologies are under intensive investigation including fixed relays, mobile relays, as well as mobile fixed relays. There has been extensive research on multi-hop cellular networks the last few years under the form of relay networks or cooperative diversity.

The aim of the sensor network under consideration is to periodically collect all data generated by sensor nodes at a special node called a sink node. All sensor nodes monitor event and generate data periodically. A sensor node having child nodes must wait sending a packet until it receives data from all its child nodes. After receiving data from all its child nodes, the sensor node sends the packet to its parent node. This process is repeated, and all data generated at sensor nodes are finally collected at the sink node, which is located on the root of the tree.

Distributed sensor networks have been discussed for more than 30 years, but the vision of wireless sensor networks has been brought into reality only by the recent advances in wireless communications and electronics, which have enabled the development of low-cost, low-power and multi-functional sensors that are small in size and communicate over short distances. Today, cheap, smart sensors, networked through wireless links and deployed in large numbers, provide unprecedented opportunities for monitoring and controlling homes, cities, and the environment. In addition, networked sensors have a broad spectrum of applications in the defense area, generating new capabilities for reconnaissance and surveillance as well as other tactical applications.

5 Backpressure Routing

Backpressure routing refers to an algorithm for dynamically routing traffic over a multi-hop network by using congestion gradients. The algorithm can be applied to wireless communication networks, including sensor networks, mobile ad-hoc networks (MANETS), and heterogeneous networks with wireless and wire line components. Backpressure principles can also be applied to other areas, such as to the study of product assembly systems and processing networks. This article focuses on communication networks, where packets from multiple data streams arrive and must be delivered to appropriate destinations. The backpressure algorithm operates in slotted time, and every slot it seeks to route data in directions that maximize the differential backlog between neighboring nodes. This is similar to how water flows through a network of pipes via pressure gradients. However, the backpressure algorithm can be applied to multi-commodity networks (where different packets may have different destinations), and to networks where transmission rates can be selected from a set of (possibly time-varying) options. Attractive features of the backpressure algorithm are: (i) it leads to maximum network throughput, (ii) it is provably robust to time-varying network conditions, (iii) it can be implemented without knowing traffic arrival rates or channel state probabilities. However, the algorithm may introduce large delays, and may be difficult to implement exactly in networks with interference. Modifications of backpressure that reduce delay and simplify implementation are described below under Improving Delay and Distributed Backpressure.

Backpressure routing has mainly been studied in a theoretical context. In practice, ad-hoc wireless networks have typically implemented alternative routing methods based on shortest path computations or network flooding, such as Ad Hoc on-Demand Distance Vector Routing (AODV), Geographic Routing, and Extremely Opportunistic Routing (ExOR). However, the mathematical optimality properties of backpressure have motivated recent experimental demonstrations of its use on wireless test beds at the University of Southern California and at North Carolina State University

The original backpressure algorithm was developed by Tassiulas and Ephremides. They considered a multi-hop packet radio network with random packet arrivals and a fixed set of link selection options. Their algorithm consisted of a max-weight link selection stage and a differential backlog routing stage. They did not call their algorithm "backpressure," as, at the time of the Tassiulas-Ephremides work, the term "backpressure" had a different meaning in the area of data networks (it referred to a class of congestion-based flow control techniques). The Tassiulas-Ephremides algorithm was first called "backpressure" in and where the algorithm was extended to treat networks with mobility, including ad-hoc mobile networks. An algorithm related to backpressure, designed for computing multi-commodity network flows, was developed in. Backpressure is mathematically analyzed via the theory of Lyapunov drift, and has been unified with utility optimization techniques in (see also Backpressure with Utility Optimization and Penalty Minimization).

Backpressure routing is designed to make decisions that (roughly) minimize the sum of squares of queue backlogs in the network from one timeslot to the next. The precise mathematical development of this technique is described in later sections. This section describes the general network model and the operation of backpressure routing with respect to this model.

6 IMPROVING DELAY

It is important to note that the backpressure algorithm does not use any pre-specified paths. Paths are learned dynamically, and may be different for different packets. Delay can be very large, particularly when the system is lightly loaded so that there is not enough pressure to push data towards the destination. As an example, suppose one packet enters the network, and nothing else ever enters. This packet may take a loopy walk through the network and never arrive at its destination because no pressure gradients build up. This does not contradict the throughput optimality or stability properties of backpressure because the network has at most one packet at any time and hence is trivially stable (achieving a delivery rate of 0, equal to the arrival rate).

It is also possible to implement backpressure on a set of pre-specified paths that can be used. This can restrict the capacity region, but might improve in-order delivery and delay. Another way to improve delay, without affecting the capacity region, is to use the enhanced version of backpressure developed in, which adds a "differential progress-to-destination" term to the backpressure weight Wab(t). Simulations of this are given in. Note that backpressure does not require First-in-First-Out (FIFO) service at the queues. It has been observed in implementations and analysis in that using Last-in-First-Out (LIFO) service can dramatically improve delay for the vast majority of packets, without affecting throughput.

7 SYSTEM ARCHITECTURE

Due to the scarcity of wireless bandwidth resources, it is important to efficiently utilize resources to support high-throughput, high-quality communications over multihop wireless networks. In this context, good routing and scheduling algorithms are needed to dynamically allocate wireless resources to maximize the network throughput region. To address this, throughput-optimal1 routing and scheduling, first developed in the seminal work of, has been extensively studied. With the significant increase of real-time traffic, end-to-end delay becomes very important in network algorithm design. The traditional back-pressure algorithm stabilizes the network by exploiting all possible paths between source–destination pairs.

This project proposes a new optimal routing/scheduling back-pressure algorithm that not only guarantees network stability (throughput optimality), but also adaptively selects a set of optimal routes based on shortest-path information in order to minimize average path lengths between each source and destination pair. Our results indicate that under the traditional back-pressure algorithm, the end-to-end packet delay first decreases and then increases as a function of the network load (arrival rate). The proposed particle swarm optimization based back pressure algorithm adaptively selects a set of routes according to the traffic load and energy efficiency so that long paths are used only when necessary, thus resulting in much smaller end-to-end packet delays as compared to the traditional back-pressure algorithm. Shortest-path-aided back-pressure algorithm that not only guarantees the network stability (throughput-optimal), but also adaptively selects the optimal routes according to the traffic demand. When the traffic is light, the algorithm only uses shortest paths; when the traffic increases, more paths are exploited to support the traffic. Shortest-path-aided back-pressure algorithm leads to a much smaller end-to-end delay compared to the traditional back-pressure algorithm.

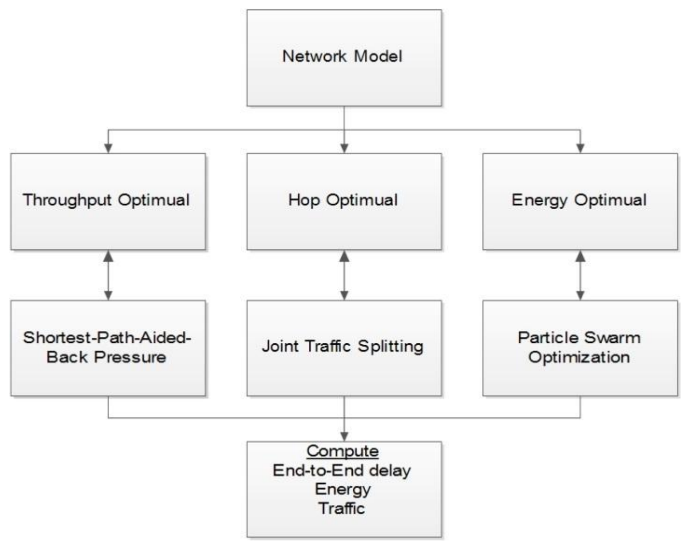

Fig.1.System Architecture

First we create a network model assign number of nodes, position, energy, and data rate. Throughput-optimal routing/scheduling for multicast flows has been considered. The idea of using the shortest path information to enhance the performance of the back-pressure algorithm has been studied. The main difference is that the proposed algorithm provably minimizes the average path lengths, whereas the enhanced algorithm in uses the shortest path information in a heuristic manner. A hop-optimal algorithm is that such an algorithm will not only minimize the number of transmissions required to support the traffic, but also reduce the average end-to-end transmission delay. The parameter in the traffic splitting is a tuning parameter, which plays an important role when the proposed algorithm is used in a stochastic network (stochastic arrivals and fading channels). In theory, the value of controls the tradeoff between the overall backlog in the network and the optimality of the steady-state resource allocation solution.

The algorithm asymptotically solves the hop minimization problem as, but pays a price of increasingly large backlogs in the network. In previous works on stochastic control of wireless networks similar tuning parameters have also been introduced. Economic usage of energy is a critical issue in WSNs. Communication is the most energy expensive activity a node performs. Energy required to transmit varies exponentially with transmission distance; therefore, it is customary to use multi-hop communication in WSNs. A WSN's life-time largely depends on how efficiently it carries a data packet from its source to its destination. Pso algorithm is used to optimize energy in this project.

8 Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called lbest. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its pbest and lbest locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and lbest locations. In past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods.

Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement.

9 Algorithm

Formally, let $f: \mathbb{R}^n \rightarrow \mathbb{R}$ be the fitness or cost function which must be minimized. The function takes a candidate solution as argument in the form of a vector of real numbers and produces a real number as output which indicates the fitness of the given candidate solution. The gradient of f is not known. The goal is to find a solution a for which $f(a) \leq f(b)$ for all b in the search-space, which would mean a is the global minimum. Maximization can be performed by considering the function $h = -f$ instead.

Let S be the number of particles in the swarm, each having a position $x_i \in \mathbb{R}^n$ in the search-space and a velocity $v_i \in \mathbb{R}^n$. Let p_i be the best known position of particle i and let g be the best known position of the entire swarm. A basic PSO algorithm is then:

For each particle i = 1, ..., S do:

- Initialize the particle's position with a uniformly distributed random vector: $x_i \sim U(b_{lo}, b_{up})$, where b_{lo} and b_{up} are the lower and upper boundaries of the search-space.
- Initialize the particle's best known position to its initial position: $p_i \leftarrow x_i$
- If $(f(p_i) < f(g))$ update the swarm's best known position: $g \leftarrow p_i$
- Initialize the particle's velocity: $v_i \sim U(-|b_{up}-b_{lo}|, |b_{up}-b_{lo}|)$

Until a termination criterion is met (e.g. number of iterations performed, or adequate fitness reached), repeat:

For each particle i = 1, ..., S do:

- Pick random numbers: $r_p, r_g \sim U(0,1)$
- Update the particle's velocity: $v_i \leftarrow \omega\, v_i + \varphi_p\, r_p\, (p_i-x_i) + \varphi_g\, r_g\, (g-x_i)$
- Update the particle's position: $x_i \leftarrow x_i + v_i$
- If $(f(x_i) < f(p_i))$ do:
  - Update the particle's best known position: $p_i \leftarrow x_i$
  - If $(f(p_i) < f(g))$ update the swarm's best known position: $g \leftarrow p_i$

Now g holds the best found solution.

The parameters ω, φ_p, and φ_g are selected by the practitioner and control the behaviour and efficacy of the PSO method.

10 Flow Chart

A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solutions (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered.

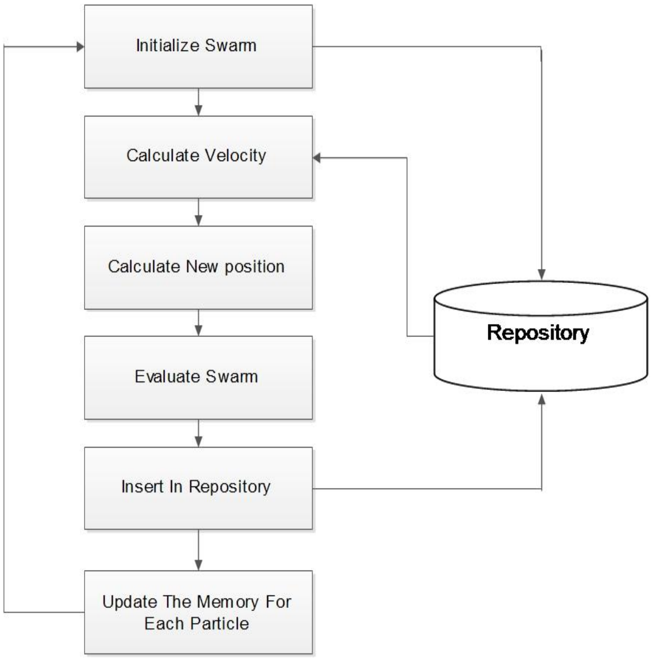

Fig.2 Flow Chart

11 Conclusion

The scheduling/routing algorithms we developed use the shortest-path information in finding the next hop. The length of a path is defined to be the number of hops along the path. Instead of counting the number of hops, we can assign different weights to different links. The weight can be the propagation time of the link, the geographic distance between two nodes, etc in the joint traffic-splitting and shortest-path-aided back-pressure algorithm; we impose artificial hop constraints in order to minimize the average path length. The proposed particle swarm optimization based back pressure algorithm adaptively selects a set of routes according to the traffic load and energy efficiency so that long paths are used only when necessary, thus resulting in much smaller end-to-end packet delays as compared to the traditional back-pressure algorithm.

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Authors Biography

T. Antony Thobias received his B.E (Electronics and Communication) Degree in the year 2005, from C.S.I Institute of Technology, Kanyakumari - Affiliated to Anna University, Chennai. Currently he is pursuing M.E Degree in Vel Tech Multi Tech Dr.RR Dr.SR Engineering College, Chennai, affiliated to Anna University. His Area of interest include Wireless Network.

P. Vijayanand received his B.E from Pallavan College of Engineering, Kanchepuram in 2005 and M.Tech degree from Sathyabama University, Chennai in 2011. He is currently working as an Assistant Professor in Information Technology at Vel Tech Multi Tech Dr.RR Dr.SR Engineering College, affiliated to Anna University, Chennai. He has 4 years of teaching experience in Engineering College. His area of interest includes Wireless Networks.

S.Manikandan received his B.E from Mount Zion College of Engineering and Technology, Kanchepuram in 2006 and M.Tech degree from Anna University, Chennai in 2009. He is currently working as an Assistant Professor in Information Technology at Vel Tech Multi Tech Dr.RR Dr.SR Engineering College, affiliated to Anna University, Chennai. He has 3 years of teaching experience in Engineering College. His area of interest includes Wireless Networks.