Unit-IV

Wireless Geolocation Systems

* **What is Wireless Geolocation?**

- Geoloc^n can simply be defined as the ability to locate a device or human being's position in terms of well known global or local coordinates. The coordinates can be latitude & longitude on the earth's surface with a height above the earth. The coordinates can also be relative and local - for example, floor of a building etc.

- Accuracy refers to the error in distance from determined and actual positions. Precision refers to the fraction of time that the error is smaller than the above number.

- The term "location-based service" is used to denote services provided to mobile users based on their geographic location, position, or known presence. These are primarily based on a geolocation infrastructure and system put in place to obtain loc^n info. of users.

- Commercially, content, advertising and personalization services that are loc^n dependent are Indoor geoloc^n appl^{n}s traditionally have been directed towards locating people & assets within buildings. The so-called personal locator services (PLS) that could also operate outdoors, employ a locator device that reside with a person whose loc^n is to be determined.

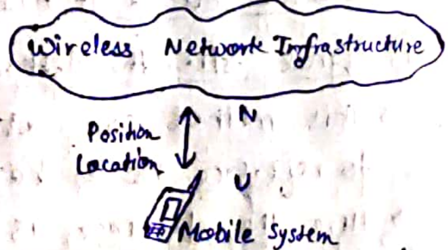
- There are several outdoor geoloc^n appl^{n}s, the most common of which is application of locating ones own self using GPS while traveling on the road. Intelligent Transportation Systems (ITS) refer to the ability to autonomously navigate vehicles while making use of the latest traffic info., road cond^{n}s, travel duration etc.

* **Need for Geolocation**

- The geoloc^n of mobile users could provide services like:
  → Emergency service for subscriber safety
  → Location sensitive billing
  → Cellular fraud detection
  → Intelligent transport system services
  → Efficient & Effective network performance and management

* **Geolocation System Architecture**

- The two essential func^{n}al ingredients for position loc^n are the loc^n estimation of the MS U & this information with appropriate attribute shared with network N.

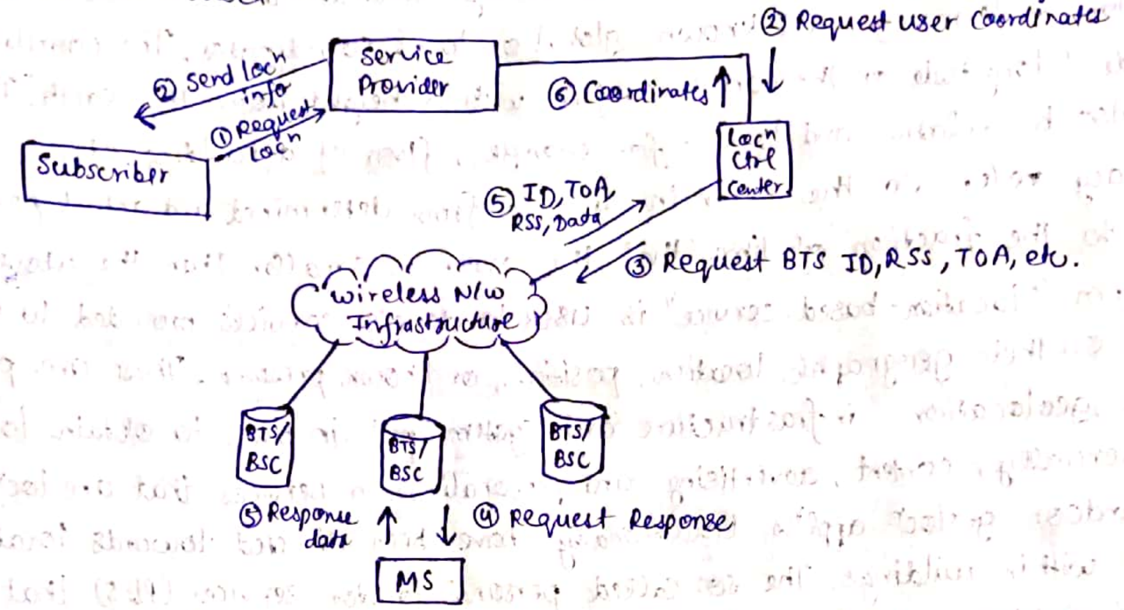


Fundamental Architecture of Geoloc^n system

- There are two ways in which the actual estimate of the loc^n can be obtained. In a self-positioning system, the MS locates its own position using measurements of its distance or direction from known loc^{n}s of transmitters.

- Self-positioning systems are often referred to as mobile-based or terminal-centric

- Positioning systems.
In remote positioning systems, receivers at known locⁿs on a n/w together compute the locⁿ of a mobile transmitter using measurements of the distance or direction of this mobile from each of the receivers. Remote positioning systems are also called n/w-based or n/w-centric positioning systems.



General Architecture of a Geolocation System

- A geolocⁿ service provider provides locⁿ info & locⁿ aware services to subscribers.
- Upon a request from a subscriber for locⁿ info about an MS, the service provider will contact a locⁿ ctrl centre querying it for coordinates of MS. The locⁿ ctrl centre will gather info. required to compute the MS's locⁿ. Depending on past infoⁿ about MS, a set of BS(s) could be used to page MS, & directly or indirectly obtain the locⁿ parameters. These are sometimes called Geolocⁿ Base Stations (GBS). Once this info is collected, the locⁿ ctrl centre can determine the locⁿ of mobile with certain accuracy & convey this infoⁿ to service provider. The service provider will then use this infoⁿ to visually display the MS's locⁿ to the subscriber. Sometimes the subscriber could be MS itself, in which case the messaging & architecture will be simplified, especially if applⁿ involves self-positioning.

★ Technologies for Wireless Geolocation

① Distance-Based Techniques

(i) Signal Strength Method
→ This method can ~~als~~ be used for estimating the distances of an unknown node to reference nodes based on signal strength. This method can only be used with ~~RF~~ Radio signals.
→ Here the distance is estimated from path loss using radio propagation models. By knowing the transmitted power & the received power, the effective path loss can be calculated. The distance b/w. transmitter & receiver can then be obtained by converting the obtained path loss into distance appropriate path loss model that well represents the environment through which radio signal propagates.

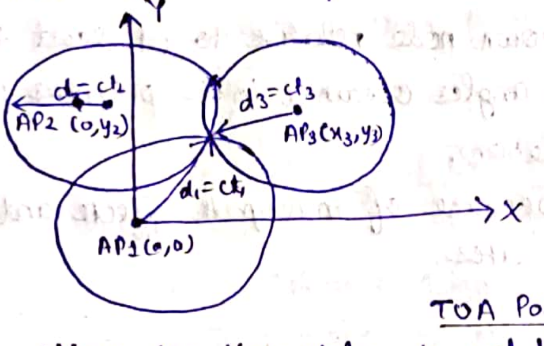
→ This method is highly unpredictable as the signal suffers from multipath, fading and shadowing effects. This method, can have measurement errors upto 50% of the range of nodes.

→ This technique results in a low complexity receiver for a self-positioning system.

(ii) Time of Arrival (TOA)

→ In this locⁿ technique the time of arrival of the signal sent by the mobile to be positioned is measured at each receiver (access point). The propagation time of each signal is known and is proportional to the distance.

→ The measured time provides infoⁿ in a set of points around the circumference of a circle having the radius of distance between the object (mobile) and the access point. The intersection of the circles is the mobile's station. For 2-D locⁿ based on TOA, at least three access points are required.



$$d_1 = ct_1 = \sqrt{x^2 + y^2}$$

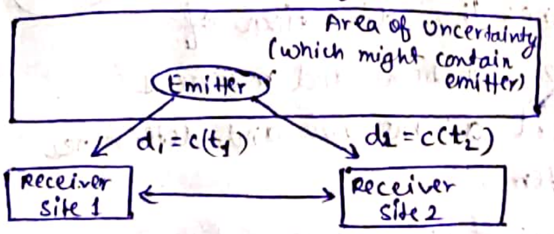
$$d_2 = ct_2 = \sqrt{x^2 + (y - y_2)^2}$$

$$d_3 = ct_3 = \sqrt{(x - x_3)^2 + (y - y_3)^2}$$

TOA Positioning Method

→ TOA utilizes the time delay to get the distance and looks for the intersection of at least three circles to estimate the locⁿ. It requires synchronization at both transmitter & receiver side. If not synched or if there is an offset in time of transmission, TOA methods cannot work properly.

→ A variant of TOA, the time difference of arrival (TDOA) scheme, calculates the target mobile's position accⁿ to time differences b/w each measurements, rather than time measurement itself as in TOA.



→ TOA & TDOA methods use geometric relⁿships based on ~~distan~~ distances or distance differences b/w a mobile station & a no. of fixed terminals to determine the position coordinates of the mobile target.

→ The TOA methods uses the transit time b/w a transmitter and a receiver directly to find difference, whereas TDOA method calculates locⁿ from differences of arrival times measured on pair of transmission paths between target and fixed terminals.

→ In TOA, locⁿ estimates are found by determining the points of intersection of circles or spheres whose centers are located at the fixed stations and the radii are estimated distances to the target. TDOA locates the target at intersections of hyperbolas or hyperboloids that are generated with foci at each fixed station of a pair.

(iii) Received Signal Phase Method

→ The received signal phase is another possible geolocation metric. With the aid of reference receivers to measure carrier phase, differential GPS (DGPS) can improve the locn accuracy from about 20 m to within 1 m compred with standard GPS, which only uses range measurements.

→ Problem associated with phase measurements lies in the ambiguity resulting from periodic property of single phase. In DGPS, the ambiguous phase measurements is used for fine-tuning the range measurement.

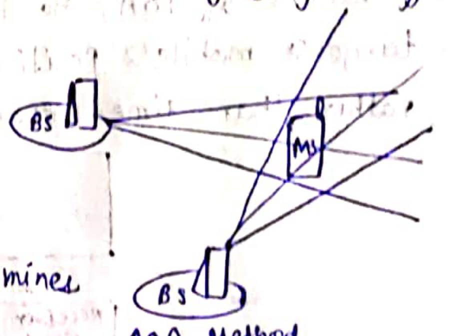
(2) Direction Based Geolocation

- The position of unknown node can be determined in two phases: angle estimation and position calculation.
- In phase one, angular bearings of unknown node relative to at least three reference nodes are estimated. From the angles obtained in the previous phase the position is estimated ~~by~~ using triangulation.
- This method cannot be used indoors because of multipath effects and it also requires costly antenna arrays at cell sites.

- Angle of Arrival (AOA) method

→ The AOA approach to distance measurement and location uses directional antennas Both broadcast & those used for eavsdropping, and for tracking wild animals that are tagged with tiny transmitters.

→ When a mobile user switches the system ON it receives the signal from different base stations, may be 3 or 4 or more. The AOA method has two or more base station for the determination. It measures the direction of signal falling on the base station and measures the angle of incidence w.r.t a normal and determines the position of the system.



AOA Method

→ Disadvantages: # Determination of system will be in error if angle of incidence is changed due to any obstacle.

The accurate locn can't be determined if mobile user is in b/w the BSs, i.e, in a straight line.

→ AOA method can provide acceptable locn accuracy.

(3) Fingerprinting-Based Techniques :- Basic elements:

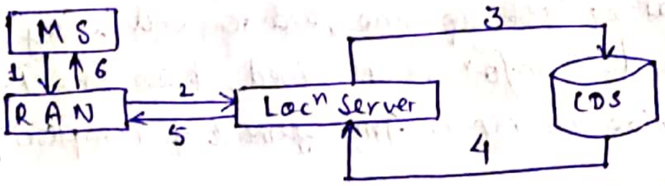
→ RF Fingerprint: This is a set of locn dependent signal parameters, available in Radio Acces NW (RAN). These parameters are locn dependent; therefore each RF fingerprint is associated with a specific position.

→ CDS : RF fingerprints are collected in-field tests or generated using simulation models, and are stored in a database called CDS, which is directly accessible to the loc^n server. Each RF finger print stored in CDS is associated with a specific ~~loc^n~~ position.

→ Location Server: This is the n/w element responsible for receiving loc^n requests, consulting the CDB, & estimating MS loc^n.

→ Reduction of Search Space within CDB : The CDB might be quite large, & analyzing all RF fingerprints might be time consuming. Thus, all fingerprinting loc^n techniques apply some method to reduce search space within CDB. As a consequence, the time required to produce a position fix is also reduced.

→ Pattern Matching: In order to estimate MS position, the loc^n server must cmp RF fingerprint measured by MS with subset of RF fingerprint stored in CDB. This comparison or pattern matching might be done using different techniques.



Schematic Diagram of a fingerprinting loc^n

- The diagram corresponds to MS originated position request. In step 1, the MS sends a position request to the loc^n server through RAN. In step 2, the RAN communicates with loc^n server, usually through a gateway. In step 3, the loc^n server queries the CDB, obtaining in step 4 the RF fingerprints, which will be compared to RF fingerprint measured by MS. The loc^n server then applies a loc^n estimation or comparison func^n to obtain MS position estimate, which is sent back to the MS through the RAN in steps 5 & 6.

* Geolocation Standards for E-911 (Enhanced-911) Services

- The options for E-911 services when they were mandated included traditional GPS or a n/w centric approach based on TDOA. GPS provides sufficient accuracy for E-911 systems. The only disadvantage of GPS is that time to first fix (TTFF) can be very long depending on what satellite constellation a MS may be able to see.
- To solve this problem, a new technique called assisted GPS (A-GPS) has been proposed whereby an entity in the cellular n/w is enabled with a GPS receiver that can see the same satellites as the MS. Due to this, the n/w entity can enable a faster TTFF. A-GPS also enables the n/w entity to detect signals with a weaker strength than an MS & sends a sensitivity assistance msg to the MS.
- An automatic loc^n ~~address~~ info^n (ALI) database is queried by PSAP with loc^n parameters & receives loc^n back along with info^n related to mobile station. A geographic info^n service (GIS) can be added to PSAP to provide a visual display pinpointing the roads, streets, addresses, jurisdiction, & so on.

* ## Performance Measures for Geolocation Services

1. One of the most important performance ~~metrics~~ measures is the accuracy by which the locn is determined. Outer position locn appln's demand a low accuracy cmpred with indoor appln's. Locn system accuracy is often defined as the area of uncertainty around the exact locn where a percentage of repeated locn measurements are reported.

2. Coverage is related to service area where, at a bare minimum, access to wireless n/w is possible. For geolocn systems, coverage corresponds to availability of a sufficient number of TOA, AOA, RSS, or fingerprint measurements to perform a locn computation.

3. Delay in triggering a locn measurement, locn algo. calculation time, n/w transmission delay, database look-up time, end-to-end delay b/w time a locn request is made & the locn infon is received, & so on. Reliability (the mean time b/w failures & mean time to repair) management & complexity are also important.

Recent Advances in Wireless Networks

* ## Ultra-Wide-Band Radio Communication

- Ultra wideband (UWB) communication is based on the transmission of very short pulses with relatively low energy. UWB technique has a fine time resolution which makes it a technology appropriate for accurate ranging. UWB waves have a good penetration capability. UWB radio signal occupies a bandwidth of more than 500 MHz or a fractional bandwidth of larger than .20. UWB is a carrier-less (i.e., baseband) radio technology & accordingly, in this radio technique no mixer is needed.

- Advantages of UWB:

(i) Have potentially low complexity & low cost: The low complexity to low cost of UWB systems arise from baseband nature of the signal transmission.

(ii) Have a noise-less signal spectrum: Due to low energy density & pseudorandom (PR) characteristics of the transmitted signal, UWB signal is noise-less ~~like~~ which ~~have~~ makes unintended detection difficult.

(iii) Are Resistant to Severe multipath & jamming: Because of large bandwidth of the transmitted signal very high multi-path resolution is achieved.

(iv) Have very good time-domain resolution allowing for locn & tracking appl's: The very narrow time-domain pulses mean that UWB radios are potentially able to offer timing precision much better than GPS & other radio systems.

- Regulatory Bodies:

→ UWB working group (UWB WG) to negotiate with FCC. Currently there are no dedicated frequency bands for UWB appl^n^s identified by ETSI (European Telecommunications Standard Institute), in the ECC (European Communication Committee) decisions or in ITU (International Telecommunications Union) Radio Regulation treaty.

- UWB Standardization in the IEEE : → IEEE 802.15.3a :

The IEEE established the 802.15.3a Study Group to define a new physical layer concept for short-range, high-data-rate appl^n^s. This alternative physical (ALT PHY) layer is intended to serve the needs of groups wishing to deploy high-data-rate appl^n^s. with a minimum data rate of 110 Mbps at 10 m, this study group intends to develop a standard to address such appl^n^s as video or multimedia links or cable replacement.

The main desired characteristics of the alternative PHY are:

(i) Coexistence of all existing IEEE 802 physical layer standards
(ii) Target data rate in excess of 100 Mbps for consumer applications
(iii) Robust multipath performance
(iv) Location awareness.
(v) Use of additional unlicensed spectrum for high-rate WPANs.

→ IEEE 802.15.4:

The IEEE established 802.15.4 study group to define a new physical layer concept for low-data-rate appl^n^s. The IEEE 802.15.4 is chartered to investigate low-data-rate sol^n^s for very low power and very low complexity systems.

One option examined by working group is utilizing UWB technology at air interface.

→ The Multiband OFDM Alliance (MBOA):

MBOA is an alliance of industry & academic partners which aims to develop physical layer and ~~MAC~~ medium access layer technologies for UWB based on OFDM techniques. The stated mission of MBOA is to develop the best overall sol^n^ for UWB-based products in compliance with worldwide regulatory requirements as well as to ensure coexistence with current & future spectrum users.

- Applications of UWB:

Intelligent WAN (IWAN)

Wireless Body Area N/w (WBAN) 

Hotspot WPAN

Outdoor Peer-to-Peer N/wing (OPPN)

Sensor Positioning, & Identification N/w (SPIN)

- UWB Transmission Schemes:

→ A traditional UWB technology is based on single-based systems employing carrier-free or impulse radio communications. Impulse radio refers to the generation of a series of impulse like waveforms, each of duration in the order of hundreds of picoseconds. Each pulse occupies a bandwidth of several gigahertz that must adhere to spectral mask requirements. The information is modulated directly into sequence of pulses using either pulse amplitude modulation (PAM) or pulse position ~~Modition~~ modulation (PPM). This type of transmission does not require additional carrier modulation as the pulse will propagate well in the radio channel.

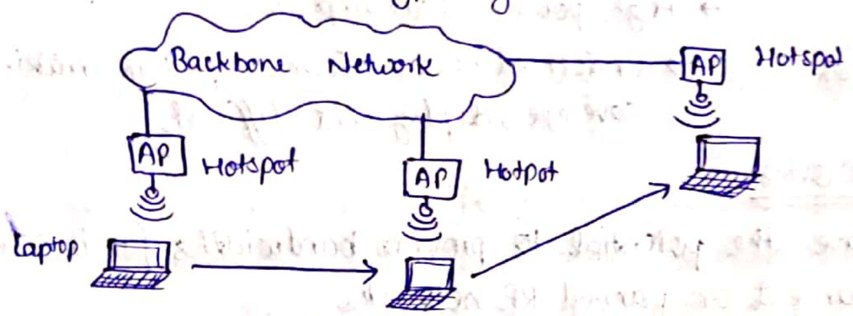
→ To overcome drawback of single-band approaches, multipath approaches were proposed. Insted of using entire UWB frequency band to transmit infoⁿ, the multiband technique divides the UWB frequency band from 3.1 to 10.6 GHz into several smaller bands, referred to as sub-bands. Each sub-band occupies a bandwidth of at least 500 MHz, in compliance with FCC regulations. By interleaving the transmitted symbols across sub-bands, multipath approach can maintain the power being transmitted as if a large GHz were being utilized. The advantage is that it allow infoⁿ to be processed over a much smaller bandwidth.

→ Multi-band Orthogonal Frequency-Division Multiplexing (OFDM) technique is efficient at collecting multipath energy in high dispersive channels. OFDM allows each subband to be divided into a set of orthogonal narrowband channels. The major difference b/w multiband OFDM & traditional OFDM is that multiband OFDM symbols are not sent continuously on a single frequency band; instead, they are interleaved over different ~~symbols~~ subbands over both time & frequency.

- Challenges:
  - (i) The transmitter power level of UWB signals is strictly limited in order for UWB devices to coexist peacefully with other wireless systems.
  - (ii) The ultrashort duration of UWB pulses leads to a large no. of resolvable multipath components of the receiver.
  - (iii) Design challenges also exist in the areas of modulation & coding techniques that are suitable for UWB systems.
  - ~~(iii)~~ (a) One design challenge is the impact of narrow band interference on UWB receivers.
  - (b) Other design challenges include scalable system architectures and spectrum flexibility.

* Wireless Fidelity

- A wireless local lan n/w (WLAN) or wireless fidelity (wifi), as it commonly known today, is the underlying technology of a wireless local n/w based on the IEEE 802.11 specification. WLANs are widely used with mobile devices, like laptops & PDAs.
- Wi-Fi technology uses wireless access points that wirelessly send and receive data using radio frequencies to and from computers and other digital devices equipped with wi-fi cards or adapters. Access points are connected to n/ws (usually via n/w cable) that are typically connected to the Intel N/w.



Broadband Wireless Access Through WLAN

- Wi-Fi has a maximum range of about 600 feet (190 meters) in open areas and 120 to 240 feet (32 to 64 metres) in closed areas.
- Setting Up a Wi-Fi:
  → The ease of installing a wifi has made it popular. Following are the steps:
  (i) Planning (ii) Choice Equipment
  (iii) Set-up (WiFi alliance):
  # Wireless Access Point (WAP) is a central point to coordinate all radio communication from all other wireless devices in the n/w. The access point also can be used as a wifi gateway.
  # Wi-Fi gateway can provide NAT addressing and a DHCP server without an existing wired n/w or a broadband modem.
  # Extend the range of n/w by using a wireless range extender or wireless repeater, if the range of the current n/w is not sufficient.
- Wi-Fi Standards:

WiFi Standard	Maximum Speed	Frequency Band	Notes
802.11a	54 Mbps	5 GHz	Less potential for RF interference than 802.11b and 802.11g; relatively shorter range
802.11b	11 Mbps	2.4 GHz	Not interoperable with 802.11a; relatively larger range (fewer Access Points required) than 802.11a
802.11g	54 Mbps	2.4 GHz	Better security features & faster data rates than 802.11b; not interoperable with 802.11a
802.11n	600 Mbps	2.4 GHz and/or 5 GHz	Interoperable with 802.11a, b & g, but for maximum performance all devices should be 802.11n

- Application:

→ Four main areas:

#LAN extension #Cross-building interconnection

#Nomadic Access # Ad hoc networks

- Issues in Wi-Fi:

→ Security threats including malicious code, DOS attacks, Trojan Horses, False Billing, worms, ransomware, malware etc.

→ Poor security concerns

→ High power consumption

→ lack of traffic prioritization

→ Unlicensed / class license spectrum making wi-fi coverage, deployment difficult.

* Optical Wireless Networks

- Optical wireless LANs have the potential to provide bandwidths far in excess to those available with current or planned RF networks.

- Optical Wireless Systems

→ There are two basic approaches to implementing optical LANs: a diffuse n/w and a directed line-of-sight (LOS) path b/w transmitter and receiver

→ A diffuse n/w is a high-power source, usually a semiconductor laser. It is modulated in order to transmit data into the coverage space. Light from this wide-angle emitter scatters from surfaces in the room to provide an optical ether. A receiver consisting of an optical collection system, a photodetector, an amplifier, and subsequent electronics is used to detect this radiation and recover the original data waveform.

→ Directed LOS paths b/w transmitter & receiver can provide data rates of hundreds of megabits per second and above, depending on particular implementation. However, the coverage provided by a single channel can be limited, so providing wide-area coverage is a significant problem. LOS channels can be blocked, as there is no alternative scattered path b/w transmitter & receiver.

→ The infrared wireless LANs fell to exploit the bandwidth available in the 1,330 nm & 1,550 nm optical spectrum windows to the fullest. Optical wireless WDM (OWWDM) system can provide a much higher bandwidth with reduced interference and high wavelength reusability the stations can connect to the OWWDM AP (access point) using control wavelength (λ_c) & obtain any data wavelength (λ_i, wher $i = 1, 2, \ldots, N$) for data transfer

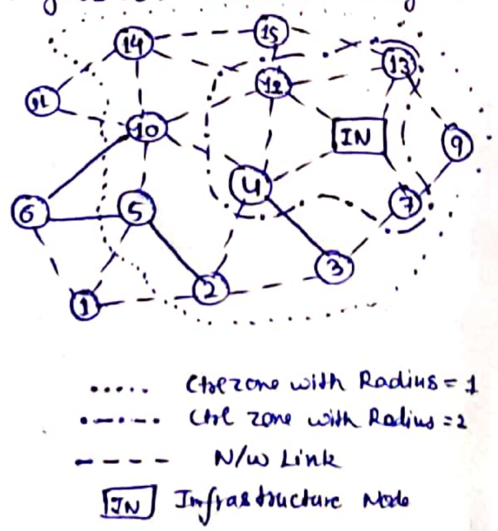
- Constraints and Data Considerations

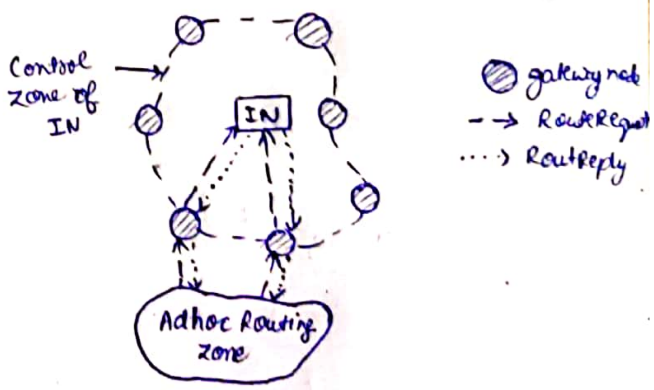
→ Source must emit optical power that meets the eye-safety regulations.

→ Filtering at the receiver can be both optical, to narrow the optical bandwidth, and electrical, to filter out noise from this ambient illumination.
→ A receiver would ideally have high optical gain. As receiver & transmitter change their locations, the angle at which light enters this receiver system will change, so the ideal receiver will also have a wide field of view.
→ Segmentation of the detector into an array of smaller detectors allow the capacitance to be decreased, resulting in increasing bandwidth and other advantages.
→ Major problem for optical channels is blocking.

★ The Meghadoot Architecture

- The Meghadoot architecture is a pkt-based wireless n/w architecture for low-cost rural community n/ws.
- Traditional wireless n/ws for rural telephony require extensive infrastructure for service deployment. The high investment and low revenue prospects in rural regions, discourage commercial service providers from providing communication services in the rural regions.
- Pkt based radio n/ws are considered as an ideal alternative for low-cost community n/ws, both in urban developed environments and also in the rural regions.
- The major objectives of the Meghadoot project are:
  (i) to develop a fully distributed pkt-based hybrid wireless n/w that can carry voice and data traffic,
  (ii) to provide a low-cost communication system in the rural regions, and
  (iii) to provide an alternate low-cost communication n/w for urban environments.
- Meghadoot uses a routing called infrastructure-based ad hoc routing protocol (IBAR):





Meghadoot Architecture

→ The Infrastructure Node (IN) ctrls the routing process in its-hop neighbourhood. Any node registered to the IN assumes that the routing and other ctrl activities would be taken care of by IN and hence it stays away from initiating its own path-finding process.
→ Nodes that are not under the ctrl of IN operate in the Ad hoc node and hence self-managed.

→ Meghadoot requires the Gateway Nodes (GN) to hold additional responsibility of interfacing the nodes in Adhoc routing zone to the IN in order to efficiently find routes to nodes inside the ctrl zone of the IN.

→ Nodes in the Adhoc routing zone broadcast RouteRequest (RReq) pkts in order to find a path to the dest. Every intermediate node forwards it unit dest. reached. When dest. nodes receives the pkt, it responds by sending back Route Reply (RRep) pkt.

→ The disadvantage of this protocol is the high ctrl overhead generated by the broadcast pkts used for finding path. Meghadoot aims at reducing this routing overhead with help of INs. The INs use a protocol called Ctrlled-zone Routing Protocol, which is an extension of Single Interface Multihop Cellular N/ws (SMCN) routing protocol.

→ By using the Controlled-zone Routing Protocol, the IN maintains the appx. topology of the nodes within its zone.

→ whenever a source node (say node S) in the controlled-zone needs to send a pkt to a dest. node (say node D), it sends a RReq pkt over multiple hops to the IN. The IN runs a shortest path algo. to find path to node D, and returns the path found to node S. Node S can now start using this path provided by IN.

→ When a path break is detected by source node, it sends a new RReq pkt to the IN for reconfiguring the broken path. If an intermediate node detects a path break, it sends a Route Error (RErr) pkt to the IN, upon reception of which the IN obtains a new path & informs the source node.