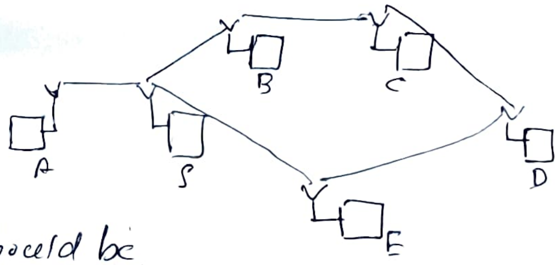
Routing Protocols :

Objective : In multihop n/work intermediate nodes relay packets from source to destination node. These intermediate nodes has to decide which neighbor to forward the incoming packet that is not destined to intermediate node. (Routing tables provide the most appropriate neighbor for a packet destination) Construction and maintenance of routing table is a task distributed routing protocol. Therefore routing protocol discusses mechanism for routing and forwarding when destination of a packet is identified by unique node identifier, set of identifiers or when all nodes in the n/work shall receive a packet.

→ Example of an identifier will be position information, which can identify both individual & group of nodes

Forms of (forwarding & routing):

The figure shows a network where the intermediate node as well as the source node has to decide to which neighboring node an incoming packet should be passed on so that the packet eventually reaches the destination.



→ This (act of passing) is called forwarding and different options for forwarding process are flood, gossiping, controlled flooding, routing tables etc.

Flood: This is the simplest forwarding where incoming packet is send to all neighbors as long as n/work source and destination in same connected component. (The packet is sure to arrive destination.) To avoid endless packet circulation node should only forward those packet that has not seen yet (unique identifier and sequence numbers in packet). Also packet has expiry time & max m. hops) to avoid needless propagation of packet (if destination node is not reachable)

Gossiping: Here packet is forwarded to arbitrary one. Such gossiping allow random traversing of packet in n/work with the hope of finding the destination. In this case the packet delay can be substantially larger.

Though forwarding schemes are simple their performance in terms of number of sent packets or delay is poor. This is because it ignores N/ok topology i.e without knowing that node A & D are far away from each other, the source 'S' has no mean of avoiding it while forwarding its own packet.

→ Hence, the information about suitability of neighbor in forwarding process is required. Suitability of neighbor is captured by the cost it incurs to send a packet to its destination via particular neighbor. (The cost is determined through number of hops and minimal energy required to reach the destination via a given neighbor). Each node collects these costs in routing tables. (computationaly intensive for large no of nodes)

Node S' routing table

Destination	Next-hop neighbor	Cost
A	A	1
D	A	3
D	B	3
D	E	2
E	E	2

Node B's routing table

Destination	Next-hop neighbor	Cost
A	S	2
	C	2
D	S	3
D	A	2
E	C	3
E		

→ Routing algorithms are used to determine routing tables with routing protocols. The protocols are either (i) table-driven (more accurate) or proactive protocols which are conservative protocols in way they try to keep accurate information in routing tables. ii) on-demand protocols which do not attempt to maintain routing tables at all times but only construct them when a packet is sent to destination for which no routing information is available.

→ Apart from the unicast case where one node sends packets to another uniquely identified node, both broadcasting (sending to all node in a network) and multicasting (sending a specified group of nodes) are important tasks in WSNs. One way of defining group is specifying a geographic region such that all node in region receive the packet. This is described as geographic routing.

Gossiping and (agent) based unicast forwarding

Random forwarding — Random walk

This forwarding scheme work without routing tables, either because of overhead to create tables is deemed Prohibitive (when a node only issues a command and doesn't expect any answers or these tables are to be constructed in first place.

→ The approaches taken here try to find a forwarding set without recurring to topology-control mechanisms but try to solve strictly locally. The techniques followed are

(i) Randomized forwarding : Here information is spreaded in wireless n/work by gossiping mechanism. The key Parameter here is the Probability with which a node retransmits a newly incoming message. A critical Probability value is choosen below which the gossip dies out quickly and reaches to small number of nodes. If the nodes use Probability larger than critical threshold to retransmit messages then most of the gossips reach all the nodes in n/work.

(ii) Random walks : Here a data packet is considered as an 'agent' that wanders through the n/wk to search the destination. This is called as random walk where a packet is randomly forwarded to arbitrary neighbor.

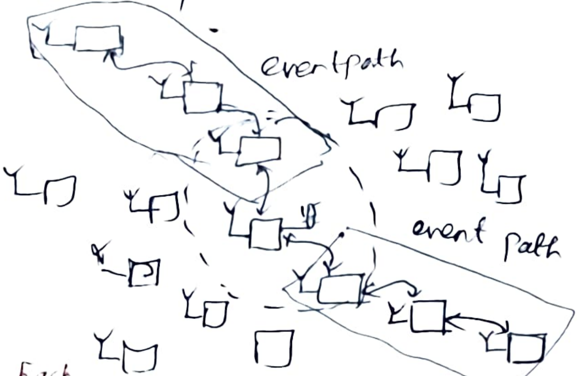
→ (These agents are sent via unicast), not via local broadcast to their next hop. The source inject several agents instead of single agent to shorten the time to arrival by parallelism. A pure random walk is inefficient for WSNs. ~~Two~~ examples of extensions to random walks are.

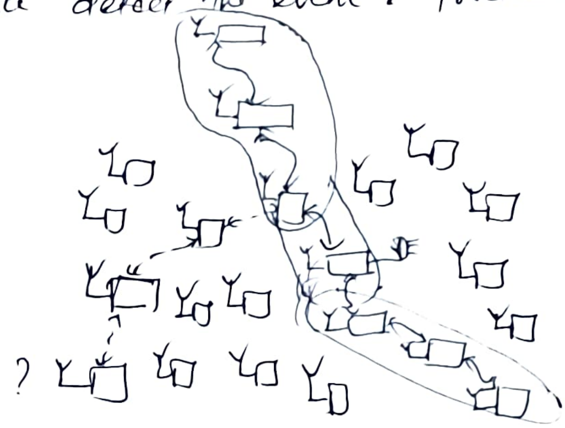
a) ~~Rou~~ Rumor routing

Assuming some sensors are interested for certain events (eg: temp. exceeding a given value) and sensor can observe it. The classical option is to flood either the query for that event or (notifications) that the event has occured through entire n/wk.

→ In rumor routing, the n/wk is not flooded with informat? about event occurance rather by ~~sending~~ Providing few paths by sending one or several agents. Each agent now Propagate from node to node and installs routing information about the event in each node that it visited.

→ for example a node in the middle detect the event & produce two event paths in the n/w.





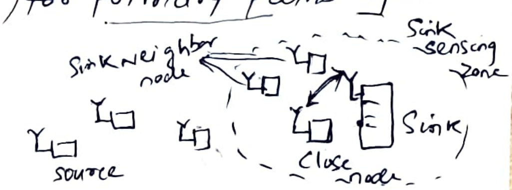
✗ Each Node uses unicast, middle node is destination

→ Once a node tries to query an event it also sends out one or more agents. these search agent forwarded through the n/w until it intersects with preinstalled event path and then knows how to find an event.

→ 2nd mechanism is random walk with known destination where the idea is to use random walk such that all possible paths in n/w used with equal probability, spreading the forwarding burden over all nodes.

Multipath unicast routing :

In unicast routing protocols a (single energy efficient path betn sink and receiver is used providing a better cost of the link. These cost balances energy for commn across link against battery capacity of nodes. [However, focusing & choosing the best path facilitating a better trade off amos energy of commn & battery capacity is not always possible, which require multiple path to balance such cost] Furthermore, multiple paths act as ('stand-bys') for primary paths upon their failure. Some methods are



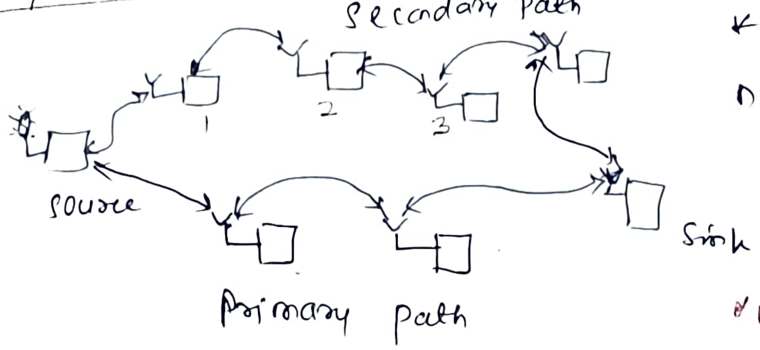
(i) Sequential Assignment Routing (SAR)

As multiple path induces overhead, it only used touely near data sink. Since nodes close to sink likely to fail quickly (all time active) due to depleted battery sources, they only require paths to use different neighbors of sink not all node that are not neighbors of sink. The SAR algorithm achieves this by constructing trees outward from each sink neighbor, so that most nodes will be part of several such trees. A Packet's actual path is then selected by the source on the basis of information about available battery resources along the path and the performance metrics (delay) of a path.

③

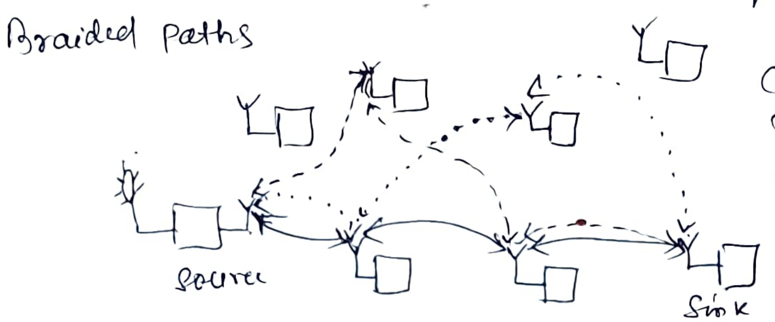
(Constructing energy-efficient Secondary Paths)

When Primary Path fails (any node of Primary path fails) the multiple Paths that act as standbys are quickly switched on. The efficiency of these paths need to be comparable to primary path. There two ways of finding multiple paths i.e disjoint paths and braided paths



* The disjointness among nodes tend to produce inefficient secondary path because it requires more energy due to hopping.
✓ Node ~~path~~ betⁿ ~~3 to sink~~ betⁿ Primary and secondary path are disjointed.

Braided paths



* Braided Paths sometimes called as meshed multipaths. The braided paths are free to use some nodes of primary paths. Due to their relaxed disjointness, these paths stay close to primary path & have close to optimal energy efficiency as Primary path.

✓ Failure of nodes is a concern in both primary & secondary paths.

(Simultaneous transmissions over multiple paths:) One multiple path may have delays 5m, other 10m, 20m.. etc.

Due to multiple paths there is some delay in detecting the packets. To reduce the delivery time and increase the delivery ratio of a packet it is also wise to (use all or (several multiple paths simultaneously.))

→ The procedure is to assume node disjoint paths and sending several copies of same packet over these paths to the destination. Obviously, this trades off betⁿ. resource consumption against packet error rates.

Randomly choosing one of several paths:

Here a packet is forwarded to next hop by randomly choosing energy proportional to the energy consumption of path over this neighbor. Let node v has neighbors $v_1, v_2 \ldots v_n$ with advertise cost $c_1, c_2 \ldots c_n$ respectively. Node v will advertise $c = n / \sum_{i=1}^{n} c_i$ as its cost and forward an incoming packet to neighbor i with probability $(1/c_i)(1/\sum_{i=1}^{n} c_i)$

Broadcast and multicast

In previous section protocols were trying to find different means to transmit data from one to another node through multiple hops. In this process some of them had to collect or distribute information to all nodes in n/wok i.e. they had to perform a broadcast operation. i.e multiple paths perform a broadcast operation. This broadcasting is a common operation in many wireless n/wok applications.

→ Also it is often necessary to distribute some data to a given subset of nodes in n/wok which is called as multicast.

broadcasting reduces the no. of forwarding nodes as one node does this.

→ Broadcasting based on how to restrict the set of forwarding nodes as much as possible while still ensuring that all nodes receive the data.

→ In multicast problem a graph $G = (V, E)$ is described by set of sources $S = (S_1, S_2 \cdot\cdot S_n)$ and for each source a set of destinations $D_i = (d_{i_1} \cdots d_{i m_i})$ for each $i = 1, \cdot\cdot n$. $D_i \subset V$. It is assumed that all destination sets are identical. Also the edges of graph are annotated with comm^n. cost. The different possibilities to construct routing structures for multicast are: source-based tree and shared, core-based

Source-based tree : Here for each source a tree is constructed rooted at a given source that contains all the destinations of this source and if necessary additional nodes of V used to ensure the for the construction of tree (i.e some other nodes apart from destinations are used).

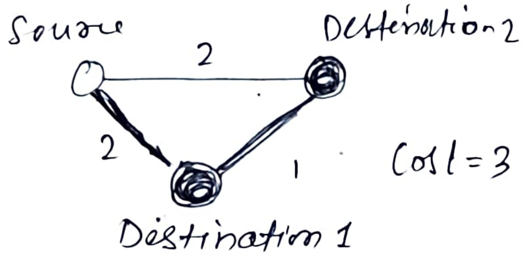
→ The selection of a tree from many is based on optimization goal which reflects link costs.

(a) For each source minimize the total cost : Try to find a tree for which the sum of all link costs is minimal. This is the Steiner tree Problem This is NP complete. The complexity is Polynomial time.

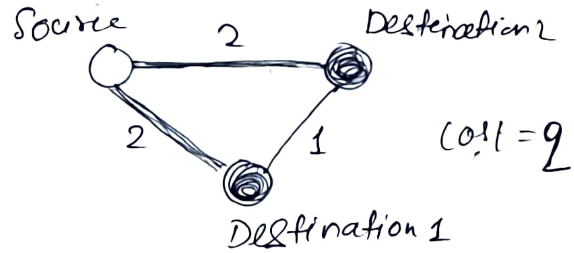
(b) For each source, minimize the maximum cost to each destination: Considering the complexity of previous optimization problem another optimizatn goal is considered. Instead of minimizing total cost of tree one can minimize cost to individual destination separately. Hence, this maps the multicast problem into repeated unicast shortest path problems.

which can be solved through routing ~~problem~~ algorithm such as Dijkstra

Steiner tree



Shortest-path tree



* Thick lines indicates link that are part of tree

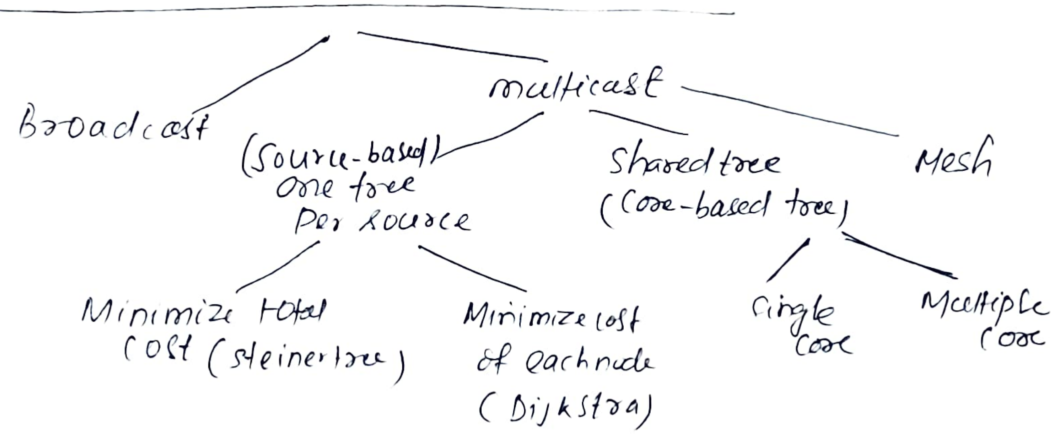
Shared, core based tree:

Construction & maintenance of dedicated tree for each source incurs considerable overhead. This can be reduced if single tree is maintained. If many sources have identical destination this can be adopted. But the demerit is the path to destination may not be (shortest for source-based tree.)

→ In order to share a tree among several sources, a (representative node) (not source & destination node) is selected and from this node the tree is constructed to contain all destination nodes. In this type tree the core node may fail and to overcome this problem multicore shared trees are also considered.

Mesh: Even if trees represent optimal routing structure, they are not redundant - failure of single link will disconnect tree. Adding additional links to tree to obtain redundancy resulting routing structure (as mesh.) Mesh requires complicated forwarding structure than simple tree does.

Overview of Possible Multicast approaches



Geographic routing:

The major idea behind such routing is

a) For many application physical location address is necessary. In such case proper routing have to be supported

b) when source, destination and intermediate nodes position are known, thus position information also assist routing process. To do so the destination node has to be specified geographically (same as a)) or as some form of mapping.

First aspect: sending data to arbitrary nodes in given region is Geocasting.

Second aspect: Position based routing (in combination with a location service)

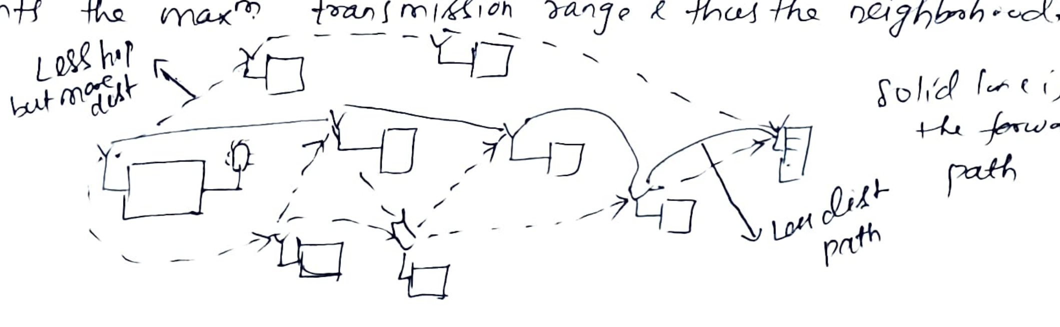
Basics of position based routing

Some forwarding strategies are

(i) Most forwarded within r

Assuming a node wants to send data packet to a node at known position and assume that every node in n/work knows its position & that of neighbors. In greedy forwarding approach the packet is forwarded to that neighbor that is closest to destination (whose position is included in packet). In this way it minimizes the remaining distance that packet has to travel. The next hop of node v toward destination d is chosen as

$$\text{next hop}(v) = \underset{u \in N(v)}{\text{argmin}} \{|ud|\},$$ where $|ud|$ indicates distance betn nodes u and d and N(v) is the set of neighbors of node v. This scheme is called most forward within r, where r represents the maxm transmission range & thus the neighborhood.

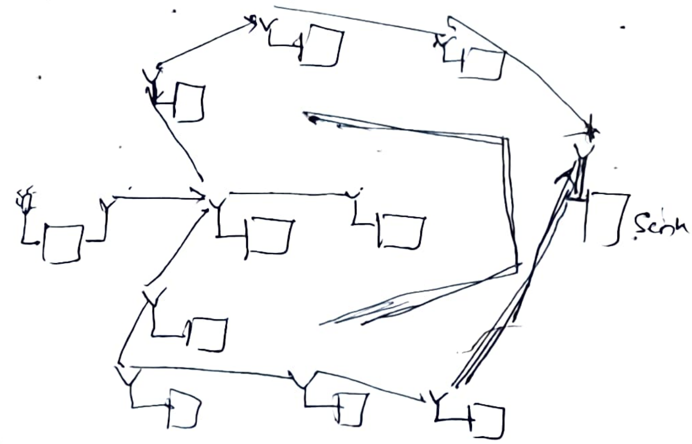


(b) Nearest with forward progress

Alternative to greedy forwarding is to choose the nearest neighbor that still results in some progress towards the destination. The rationale is to reduce collision rate & maximize expected progress per hop.

(c) Directional routing

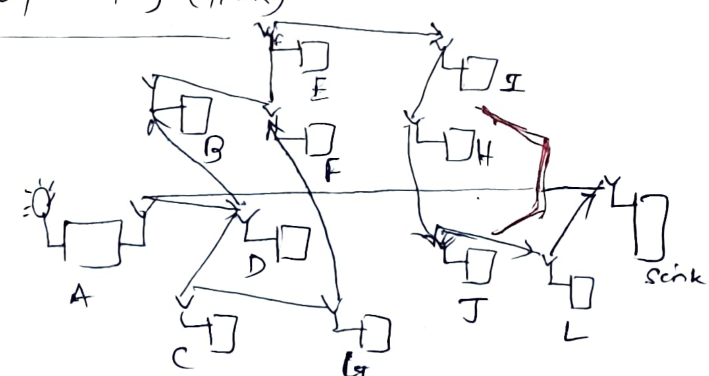
Another possibility to forward to nodes that are closer in direction rather than closer in distance. Compass routing is an ~~ex~~ example where neighbor is chosen that is closest to direct line betn. transmitter or destination. A variation would be to choose the angularly closest nodes.



Problem of dead ends

The above strategies can't deal with dead ends. If an obstacle blocks direct path betn S and D (source & destination) even if they are actually connected in network.

Right-hand rule to recover greedy routing (GPSR)



→ GPSR forwards a packet as long as possible using greedy forwarding with the most forward rule.

→ If packet can't make any more progress, the packet is switched to another routing mode: perimeter routing.

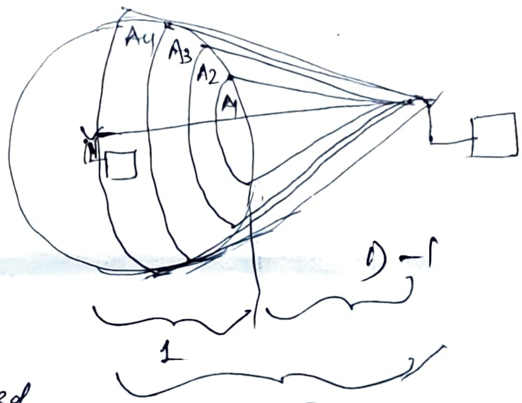
→ A perimeter is set of nodes defining a face (the largest possible region of the plane that is not cut by an edge of the graph. Perimeter routing consisting of sending packet around the face using right-hand rule.

This tech. not supported by WSNs that are not planer because this is applied to planer graph.

Randomized forwarding and adaptive node activity - GeRaF

In this scenario nodes are uniformly distributed in a plane, each node knows its position, & position of neighbors. The message is transmitted through multiple hops. Here challenge is constantly changing topology.

→ The idea is then to use receiver initiated forwarding. If node S forwarding a message without mentioning the forwarding node in the packet then the node close to destination T or in range of S will pick the message. Since the neighbors of S don't know which node are asleep a deterministic rule required. This is solved by position informed randomization.



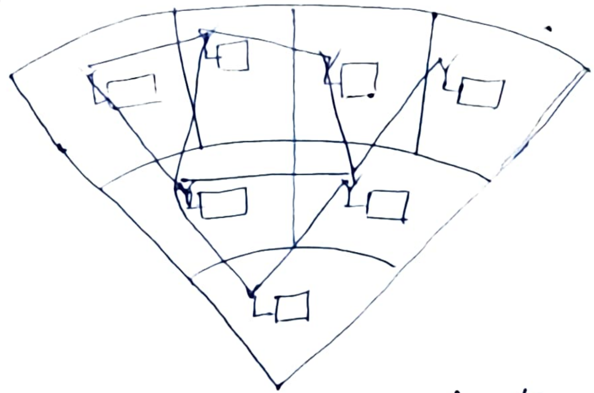
- If D is dist. bet. S & T
Let A_i be intersection with annuli $i = 1, 2 \cdots N$

→ After S broadcast packet nodes in A_1 contend for forwarding. If one node forwards packet forwarding problem is solved. If several nodes forward the packet the collision to be resolved. If no node answers, then in next time slot nodes in A_2 attempt to forward the packet and so on.

The annuli inner radious $= D - 1 + \frac{(i-1)}{N}$, $i = 1, 2, \cdots N$

~~Geographic~~ → If there is not even a node in A_N that is awake, node S simply can wait for some time and reattempt transmission, hoping that some nodes have waken up in meantime.

Geographic routing with positions :



→ Geographic routing without position information is ingenious idea

→ This method uses virtual instead of actual physical coordinates of node to facilitate routing

→ This method has 2 parts : routing using a polar coordinate system (given radious & angle) and efficient distributed construction of virtual polar cooordinates that doesn't depend on actual coordinates

→ Construct^n of virtual Polar Coordinate Space (VPCS)

Pick a node from center of n/wok & construct the spanning tree with node a route. The spanning tree defines the radious of node as number of hops bet^n. a node and root node in spanning tree.

Angle determinat^n : If a node v has n children $v_1, v_2 \dots v_n$ each with subtree size $s_1, s_2 \dots s_n$ & if node v assigned angle range $[\alpha, \beta]$ the child v_i is assigned a range of size $(\beta-\alpha) \cdot s_i / (s_1 + s_2 \dots + s_n)$

Therefore, child v_i is assigned with angle range

$[\alpha + (\beta-\alpha)(s_1 + \dots + s_{i-1}) / (s_1 + \dots + s_n) \;,\; \alpha + (\beta-\alpha)(s_1 + \dots + s_i) / (s_1 + \dots + s_n))$

Geocasting :

It represents sending data to a subset of nodes that are ~~indicated~~ located in an indicated region. It is an example of multicasting.

→ Here position information of designated region & intermediate node is exploited to increase efficiency (similar to position based routing).

Location based Multicast : (LBM)

LBM protocol uses a forwarding zone (restricted zone where packet to be forwarded) where node in this zone forward the received data packet.

This zone is defined in different ways such as :

Static zone : the smallest zone that contains both source & the entire destinat^n region.

Adaptive zone : Here forwarding ~~zone~~ node recalculates the zone using it's own position informat^n as source (forwarding node becomes source node).

This rule can only be applied if an intermediate node actually has neighbors within its newly calculated zone.

Adaptive distances :

In previous two schemes the forwarding zone is contained explicitely in each packet. However, this scheme recomputes it in each step on the basis of information about destination region and coordinates of previous hop (or the source).

* TO decide which neighbor to ~~give~~ use a given destination area certain techniques used are

Voronoi diagrams and convex hulls

Tesellating the plane

Mesh-based geocasting

Geocasting using a unicast protocol - GeoTORA

Trajectory based forwarding.