The Zone Routing Protocol (ZRP)

• Invented by Zygmunt Haas of Cornell University.

• Combines both reactive and proactive schemes.

• Finds loop free routes to the destination.

• Flat structure (as opposed to hierarchical) – why ? Hierarchical schemes can lead to congestion localization.

• Link-State routing is possible – can enable QoS.

Principle of ZRP

• ZRP limits the scope of the proactive procedure to the node's local neighborhood ✍ dramatic reduction in cost.

• The on-demand search for nodes outside the zone, albeit global, is done by querying only a subset of the nodes in the network.

• Notice that changes in network topology has local effect only.

The concept of routing zones

• Each node, individually creates its own neighborhood which it calls a routing zone.

• The zone is defined as a collection of nodes whose minimum distance (in hops) from the node in question is no greater than a value that is called the "zone radius".

• Peripheral nodes are those nodes whose minimum distance from the node in question is equal to the zone radius.

•Note that routing zones of nodes might overlap heavily.

Intra-Zone Routing Protocol (IARP)

• Could be any link state or distance vector routing protocol.

• Maintained only within a zone.

• Notice the link-state maintenance gives the ability to have QoS.

• One question that arises is how large should the zone be ?

• If it is too large, then updates too much.

• If it is too small, often resort to re-active methods.

How does IARP work ?

Node D's Zone

Border Nodes as
seen by Node D
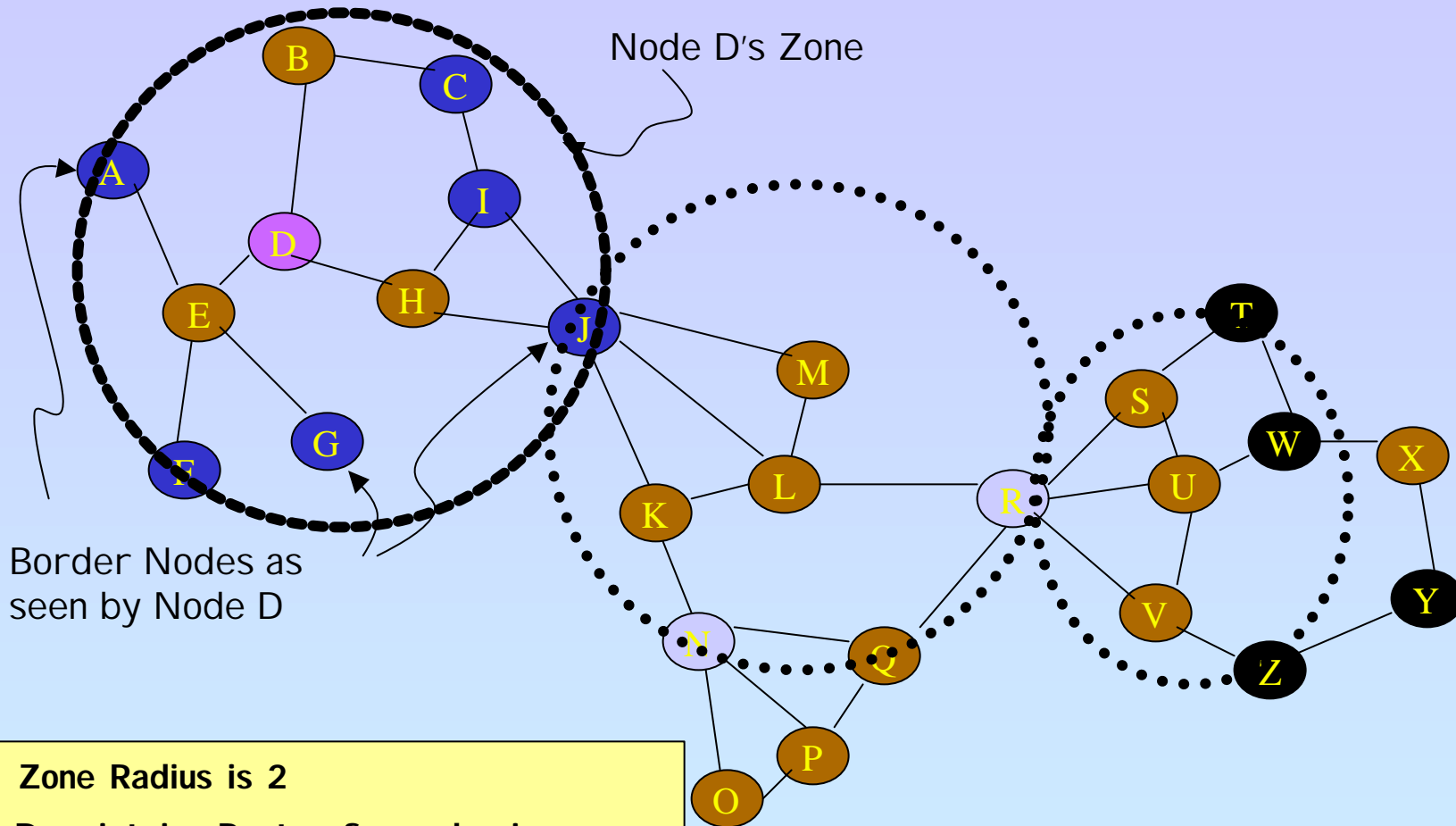
- Zone Radius is 2
- D maintains Routes for nodes in zone
--IARP e.g. D knows route to G.
- If node not found, resort to Inter
zone search.

Neighbor Discovery Protocol (NDP)

- Note that IARP requires the presence of a Neighbor Discovery Protocol.

- Hello messages are required in order to ensure that neighbors are still present.

- This helps detect link failures.

- More details in paper.

The Interzone routing protocol (IERP)

- If the IARP cannot find the destination, i.e., the destination is beyond a node's zone, the IERP is invoked.

- It is a reactive protocol that enables the discovery of the destination.

- Instead of doing a standard flood search, it exploits the structure of the routing zone to do more intelligent query dissemination.

- This is achieved by what is called "bordercasting".

Bordercasting

- The node would direct the query message out only to its peripheral nodes.

- These nodes would execute the same algorithm that the primary node executed which is:

  - Check to see if the destination can be found within its zone. (How ?).

  - If yes, send a route-reply back to the source, indicating the route to the destination.

  - If not, forward the route-request to its peripheral nodes which execute the same procedure.

How does IERP work ?

Border Nodes as
seen by Node D

Node D's Zone

B
C
A
I
D
H
E
J
F
G
M
K
L
S
T
U
W
X
R
N
Q
V
Y
Z
P
O
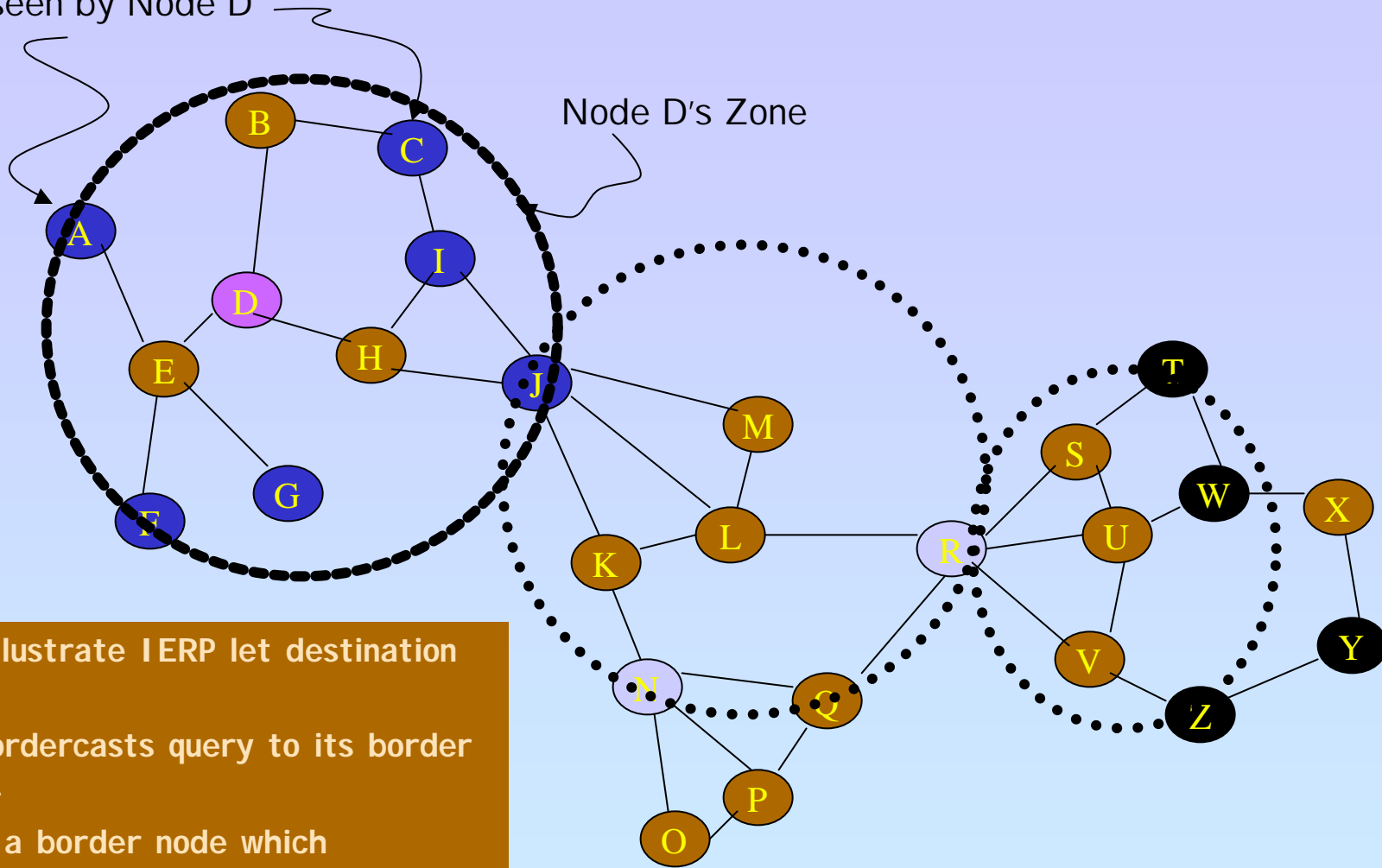
- To illustrate IERP let destination be Y

- D bordercasts query to its border nodes.

- J is a border node which bordercasts again -- to its border nodes N and R.

- R bordercasts to its border nodes W,T and Z

- Y is found.

- How is the query disseminated to the periphery nodes ?

- One possibility is to invoke some kind of multicast.

- The source based multicast tree that is formed is usually called the "bordercast tree".

Extended Routing Zone

- A node can reconstruct the bordercast trees of its interior routing zone members.

- If the basic zone radius is r, then the extended zone radius would be (2r-1).

Efficient Query Dissemination

• Notice that these queries will have to be forwarded intelligently.

• Else, there could be a flood of queries and this would result in a performance that is worse than flooding.

• What is meant by forwarded intelligently ? They should propagate outward instead of inward.

• ZRP has three schemes for query control.

• These note that redundant querying occurs when a route request packet arrives in a previously queried zone.

Advanced Query Detection (QD1 and QD2)
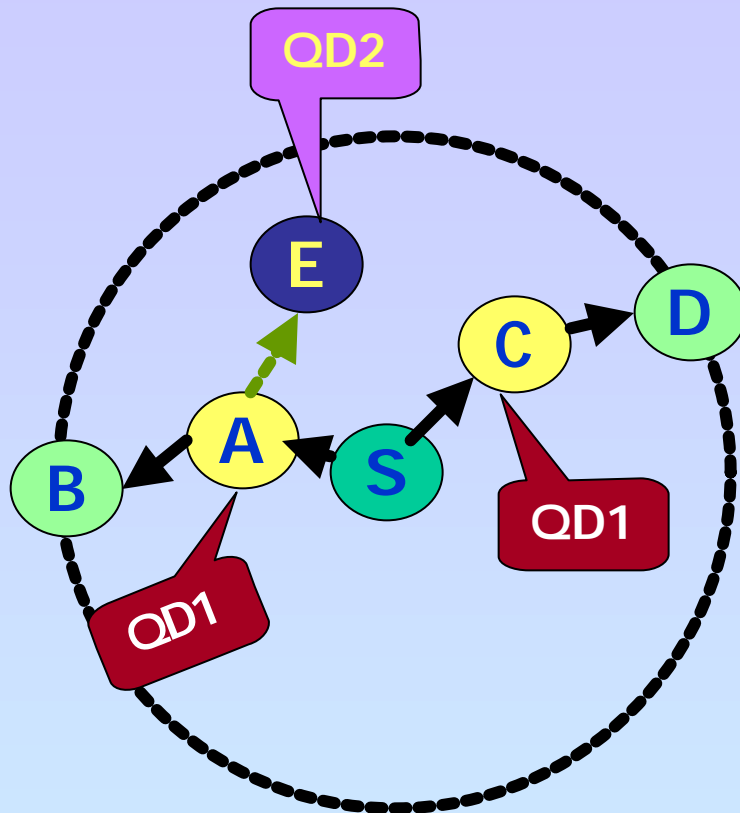
• **The first level of query detection would allow nodes to detect queries as they relay them to the edge of the routing zone. (QD1).**

• **Thus, these nodes will maintain some info with regards to the query and discard duplicate queries if seen. How can duplicate queries be identified ?**

• **The second level of query detection allows nodes to overhear queries as they are propagated (e.g. E). Node make note of overheard queries and thus, discard duplicate queries if they are received.**

Early Termination

• A node will not relay a query packet to a bordercast recipient either if that recipient lies inside the routing zone of a previously bordercast node or if it has already relayed the query to a recipient.

• This scheme is called Early Termination.

• To identify a node that lies inside the routing zone of a previously bordercast recipient, an extended routing zone has to be maintained.
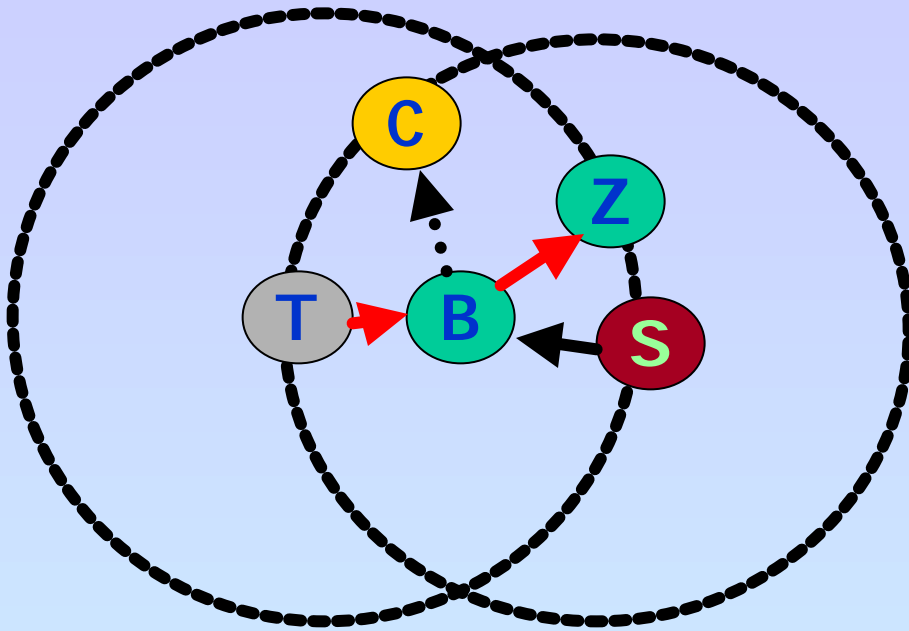
- Node B has seen a bordercast packet from T. (Sent to Z).

- Now, later on, it gets a packet from S to be bordercast to C.

- B would note that C belongs to the previously queried zone (of T) and will withhold transmission.

- It would need to know that C was in T's bordercast tree.

ADVANTAGES:

• Provides some notion of scalability.

• The absence of hierarchies eliminates definitive points of congestion.

• Did I mention that it is somewhat scalable ?

DISADVANTAGES/Questions:

• What should the zone size be ?

• Can we have variable size zones ? How can we dynamically form these zones ?

References

- Chapter 7 of book.

- Z.Haas and M. Perlman, Internet Draft : draft-zone-routing-protocol01.txt – August 1998.

- Z.J.Haas, "A Routing Protocol for Reconfigurable Wireless Networks", Proceedings of the International Conference on Universal Personal Communications (ICUPC), San Diego, 1997.

- Z.Haas and M.Perlman, "The Performance of Query Control Schemes for the Zone Routing Protocol", in Proceedings of SIGCOMM 1998.

- Z.J.Haas and M.R. Perlman, "Determining the Optimal Configuration for the Zone Routing Protocol", IEEE JSAC (Journal on Selected Areas in Comm), August 1999.
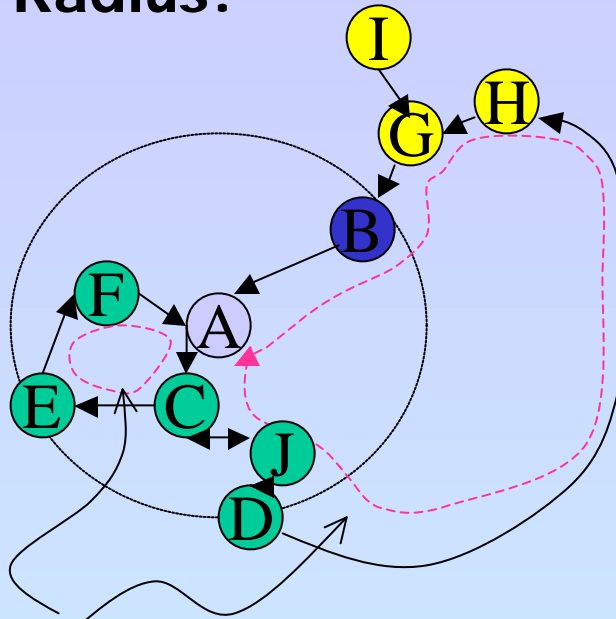
Routing in the presence of Unidirectional Links.
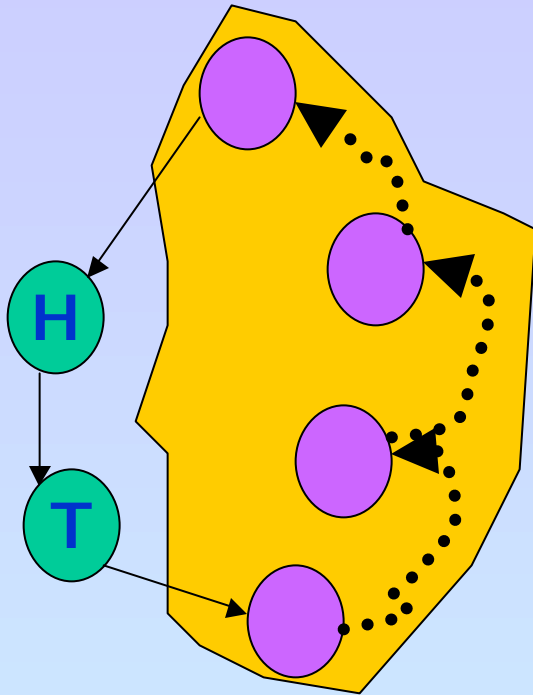
• When a unidirectional link is present, the node at the head of the link needs to be aware of the link to use it.

• No other path may be available.

• In order to make the node at the head of the link aware, a reverse path from the node at the tail of the link to the head of the link is necessary.

• The entire path, including the unidirectional link and the reverse path is known as the inclusive cycle.

SURZE: Scalable Unidirectional Routing with ZRP Extensions

Zone Radius: 3

Inclusive Cycles

• Sometimes due to the presence of unidirectional links, nodes within the zone may not be found . Example A does not know of the existence of B, because of the unidirectional link from B to A and the large inclusive cycle.

• Then, B will include its in-bound tree which tells A that the nodes, G, H and I have a path to B.

• When querying for B, A includes this information in its query packet.

• Thus, when a border node (For example D is three hops away from A and hence is a border node) searches for the destination (in this case B), it includes the alternate destinations G, H and I in its query packet. This recursive process is expected to help in faster node discovery. Disadvantage is stale information may be propagated when there is high mobility.

- Interesting questions addressed by SURZE.

- How do we now do bordercasting ?

- How should IARP work ?

- Do the Query Dissemination Schemes work ?

- Please refer to paper on my website:

P.Sinha, S.V.Krishnamurthy, and S.Dao, "Scalable Unidirectional Routing using ZRP extensions for Wireless Ad Hoc Networks", in Proceedings of Wireless Communications and Networking Conference, 2000.

Has references to work on routing in the presence of unidirectional links.

Cluster Based Networks

• Clusters are groups of nodes (in layman's terms) that are formed in accordance to some rule.

• This is similar to forming subnets in the Internet – provides a means of making the network scalable.

• The physical network is transformed into a virtual network of interconnected node clusters.

• Each cluster would have one or more "controllers" that act on its behalf.

• Decisions made by these controllers could effect access, routing and even security.

• Here we focus on routing.

References

- I am using directly the chapter 4 in the book –that too only a little bit.

- Please look at the references mentioned therein (at the end of the chapter).

- There is also some work on the "Virtual Backbone" which was done by Vaduvur Bharghavan (UIUC) – similar to clustering.

- Please refer to this if you are interested.

The Link Cluster Architecture

• **Proposed by Anthony Ephremides et al (Univ. of Maryland) and Mario Gerla (UCLA).. different versions.**

• **The ad hoc network is grouped into clusters. These clusters obviously will evolve in time.**

• **Three kind of nodes exist:**

  • **Clusterheads**

  • **Gateways**

  • **Ordinary Nodes**

Classification of Nodes

• The clusterhead schedules transmissions and allocates resources within the clusters. It might also be responsible for abstracting network state info. to reduce its quantity and variability.

• Gateways connect adjacent clusters – might be a member of both clusters or, could be a member of one with a link to a member of the other.

• Ordinary nodes --- well the nodes that are neither clusterheads or gateways are classified as ordinary.

- In the link-clustered architecture, all cluster members are within one hop of the clusterhead and two hops of one another.

- This would mean that the maximum distance between clusterheads is what ?

- It is "three hops". Why ?

- If clusterheads are different from gateways this distance is at least two hops.

The link-clustered architecture -- pictorially

Gateway that belongs
to multiple clusters

Clusterhead

Gateways that
belong to a
single cluster

Ordinary
Nodes
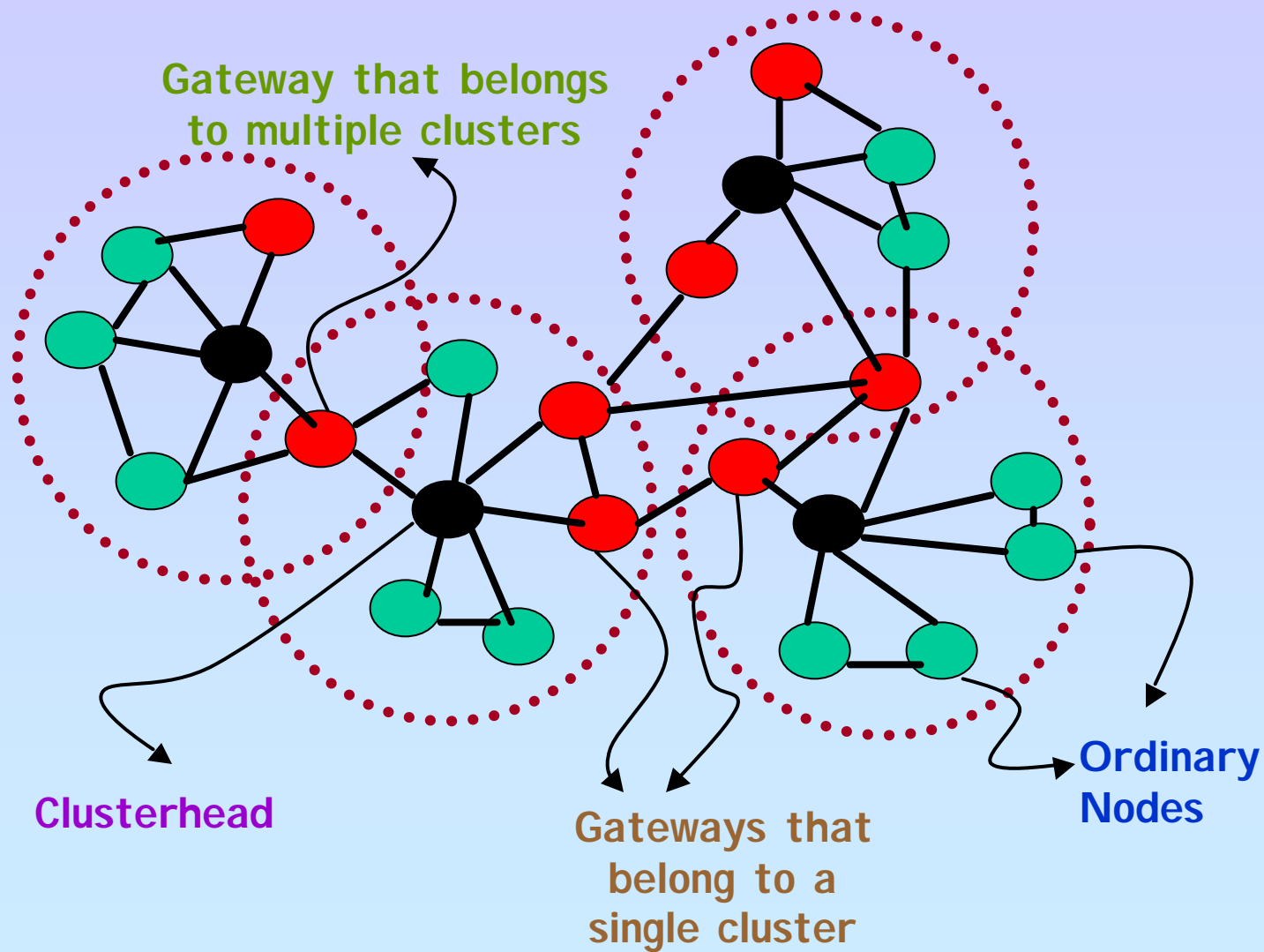
Clusterheads

- **How are clusterheads chosen ? Election !**

- **Two types of election methods:**

  - **Identifier based : Choose the node with the lowest or highest ID within a localized neighborhood as a clusterhead.**

  - **Connectivity based: Choose the node with the highest degree among a local neighborhood to be the clusterhead – break ties with ID (choose lower or higher as rule dictates).**

Election Mechanisms

• There may be a centralized version wherein a node exchanges messages with its neighbors. The node with the lowest or highest ID, or with the largest number of neighbors is chosen (consensus) for the cluster containing that node and its neighbors.

• All nodes in this cluster are excluded from further consideration.

• Process continues with other nodes in the network.

Election Mechanisms (contd.)

• There may be a **distributed version** wherein a node elects itself as a clusterhead if it has **the lowest or the highest ID** in its neighborhood.

• Otherwise it elects the bi-directionally connected neighbor with the lowest or highest ID, unless that node has already relinquished the clusterhead status to a neighbor.

• For the **connectivity based approach**, a node becomes a clusterhead if it is the most highly connected of all of its uncovered neighbors. Any node that has not yet elected its clusterhead is "uncovered". If a node has already elected some other node as a clusterhead, it cannot become a clusterhead itself.

Reactions to Mobility

- These clusters will have to be dynamically maintained with mobility.

- Mere recomputation of cluster membership and the status of the clusterhead and gateway may be sufficient.

- Other schemes possible – refer book.

Routing

• We now have a hierarchy.

• Routing through just clusterheads and gateways is possible.

• However, note that if this was done, these nodes and the links connecting these nodes get congested, while others remain underutilized.

• Furthermore, these lead to single points of failure ✍ clusterheads.

• Thus, only a backbone is formed, but the routes used may be different.

• Scalability would still be a question.

• Addressing still left for discussion – how should these clusterheads be addressed for scalable routing.

Hierarchical Routing

- The idea is to group the network into a hierarchy of clusters... e.g. clusters and superclusters.

- Two types of hierarchical routing

- Strict hierarchical routing:

    - Each node learns about the next cluster at the same level to use, in order to reach each cluster at the same level, within its next ancestral cluster.

- Quasi hierarchical routing:

    - Each node learns about the next node to use (typically the clusterhead of the new cluster), in order to reach each cluster at the same level, within its next ancestral cluster.
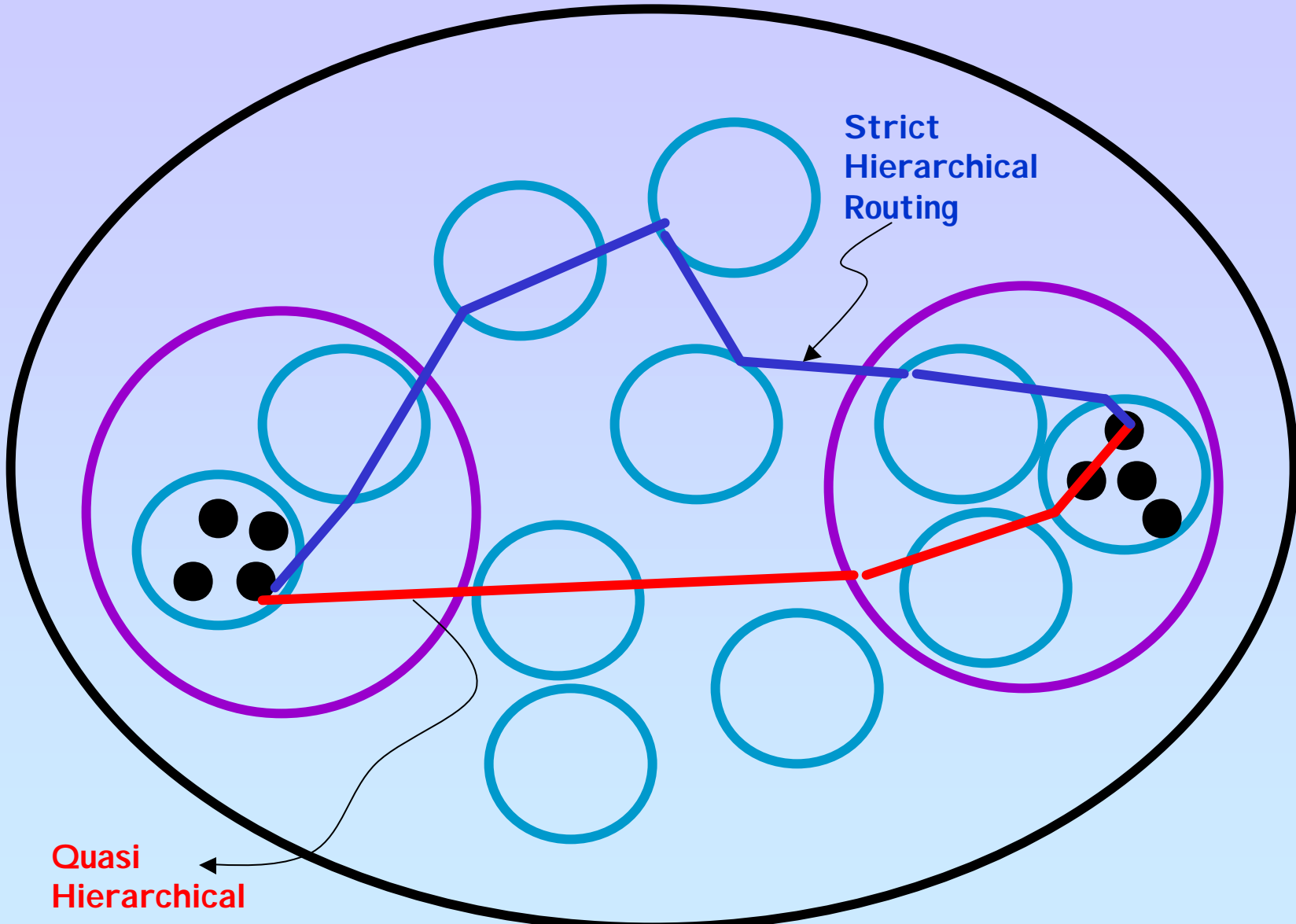
Strict Hierarchical Routing

Quasi Hierarchical Routing

- Various schemes described.

- One interesting scheme is the MMWN – Multimedia Wireless Network developed by BBN ✍ try and maintain virtual circuits; QoS provisioning; local repair.

- However, difficult to maintain hierarchy in ad hoc networks.

- How is addressing to be done ?

- Merging of clusters, splitting of clusters difficult.

- Suggest reading Chapter 4.

- Have a good weekend.