Hybridization and Adaptivity as Means to Scalability

Prince Samar and Zygmunt J. Haas

Wireless Networks Laboratory

School of Electrical & Computer Engineering

Cornell University

Why Hybrid Protocol?

- What is ***scalability?***
- ***At least two types of "scalability"***
  - of routing overhead (*control scalability*)
  - of transmission/data (*transmission scalability*)
- We consider first the *control scalability*
- *Transmission scalability* is considered in the second part of the talk ...

Why Hybrid Protocol?

- Proposition I: Let's assume that our definition of scalability is that the "network control traffic" (e.g., the routing overhead) does not increase to ∞ as the number of nodes in the network, $N \rightarrow \infty$.
- Is this a reasonable definition of scalability? …

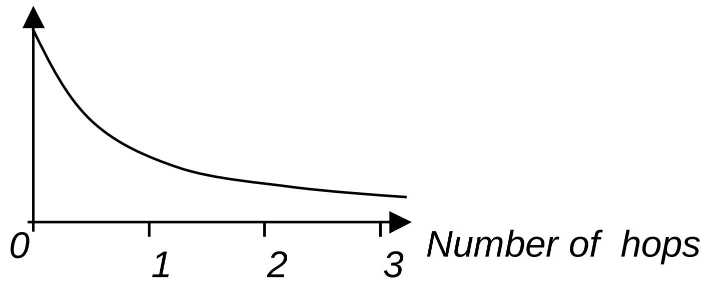
  "do not know, do not care …"
- *Networks* with *flat traffic-demand matrix* do ***not*** scale ….
  - Proactive protocols; assuming τ updates per sec and *M* "neighbors" per node, proactive protocol update traffic is: N^2*τ*M updates/sec.

Why Hybrid Protocol ? (con't)

  - Pure reactive protocols; assuming "route query rate" of λ queries/sec, reactive route discovery traffic N^2*M* λ queries/sec.
- Neither of them scale.
- Proposition II: hierarchical networks scale "better" than flat:
  - Proactive protocol: assuming τ updates per sec and *M* "cluster size" node, proactive protocol update traffic is: N^2*τ/M updates/sec.
  - Reactive protocols: assuming "route query rate" of λ queries/sec, reactive route discovery traffic N^2*λ/M queries/sec.

Why Hybrid Protocol ? (con't)

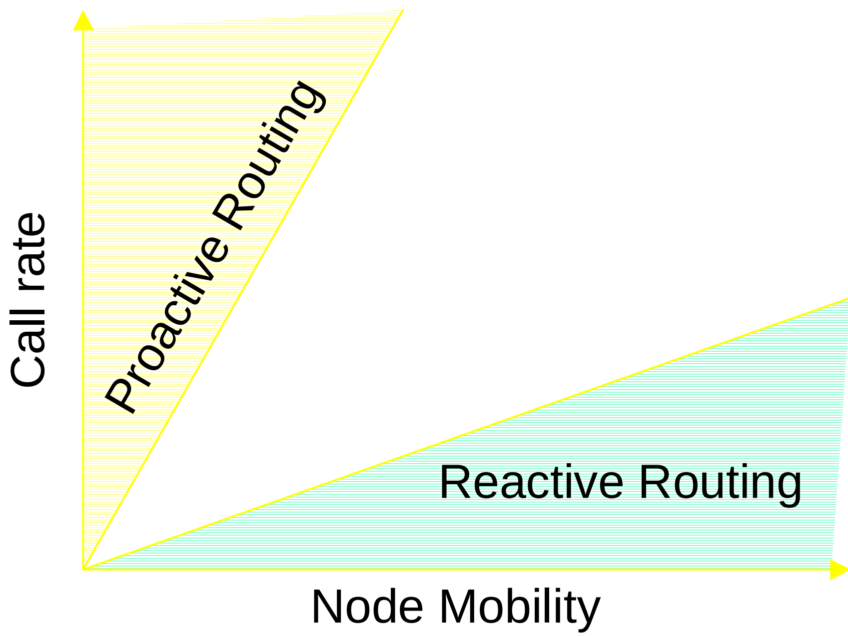
- Better, but still not scalable.
- Proposition II: Let's then assume that the traffic-demand matrix is localized.
- Examples of "localized" traffic-demand matrix:
  - a node communicates "mainly" with a fixed subset of *N*
  - a node communicates "mainly" with nodes within φ hops
  - a node communication probability decreases exponentially as a number of hops from the node increases



Why Hybrid Protocol (con't)?

- In particular, let's assume that the communication scope is "mostly" limited to φ hops.
- Then proactive scheme requires n^2*τ*M, where n is the number of nodes in a "neighborhood" of size φ hops; i.e., $n \propto \rho$, where ρ is the node density $\Rightarrow$ **constant**
- **Conclusion*: the overhead is then independent of N !***
- **The definition of a "scope" of communication is the basis for *hybridization* and the *Zone Routing Protocol -* ZRP.**

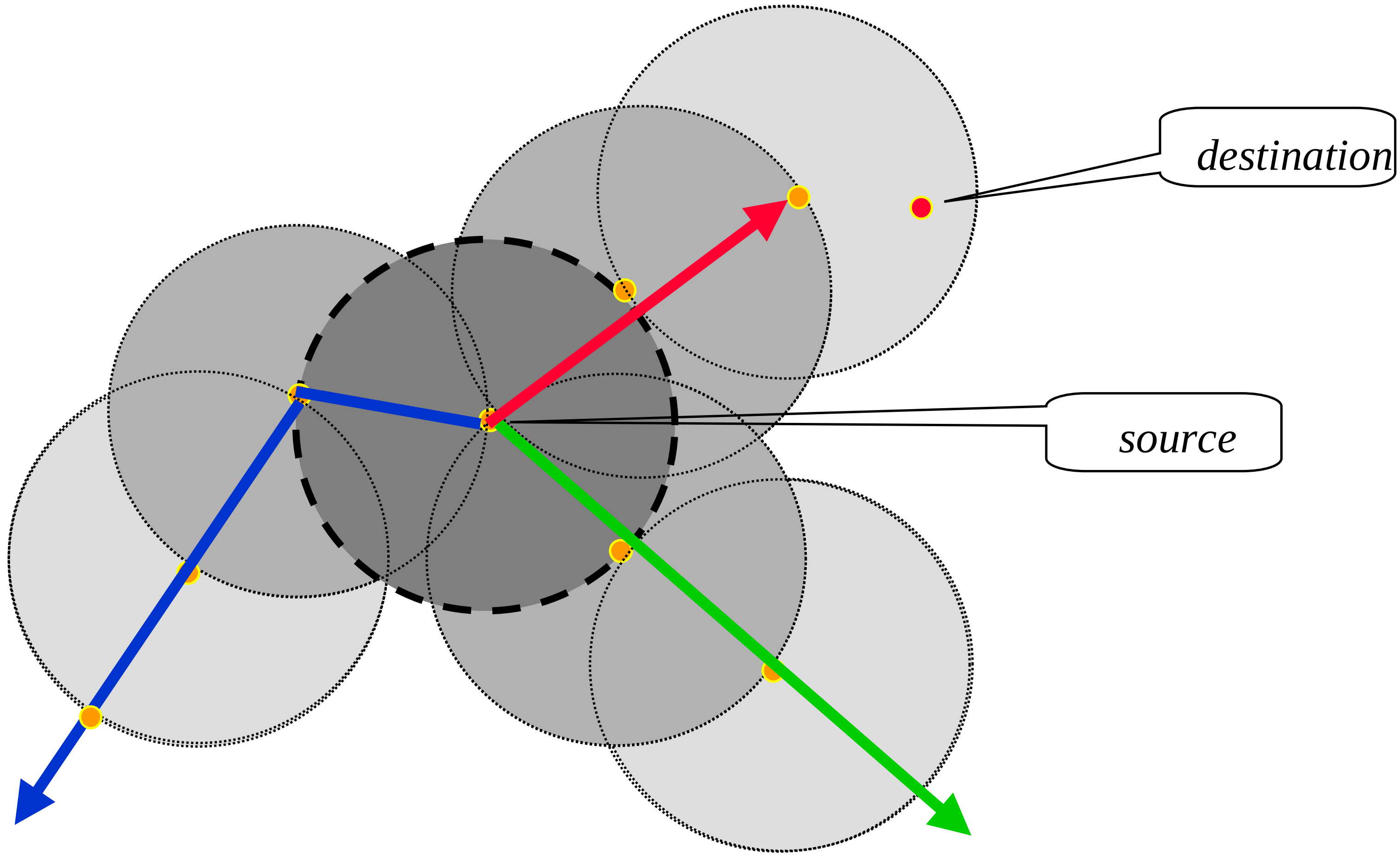
Applicability of Proactive vs. Reactive Routing in Ad Hoc Network Design Space



- Pure Proactive or Reactive protocols perform well only at the edges of ad hoc network design space.

Need a hybrid routing framework that can adaptively configure itself to match any network characteristics!

The Zone Routing Protocol (ZRP)



Introduction to the Zone Routing Protocol (ZRP)

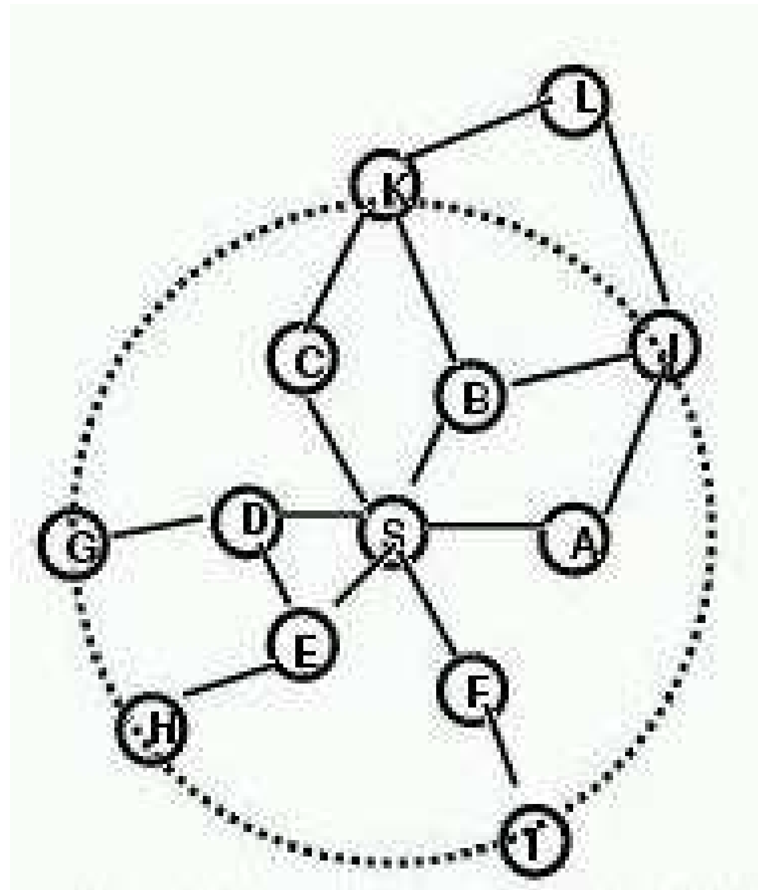
- The *Zone Routing Protocol (ZRP)* is specifically designed for Ad Hoc Networks. It is a hybrid of the reactive and proactive protocols and works on the concept of routing zones to efficiently route the query to the destination.

- In ZRP, a node proactively maintains routes to destinations within a local neighborhood, called the *routing zone*, using a table-driven protocol, called the *IntrAzone Routing Protocol (IARP)*.

- The *IntErzone Routing Protocol (IERP)*, an on-demand protocol, reactively discovers routes to destinations located beyond a node’s routing zone.

The Notion of a Routing Zone

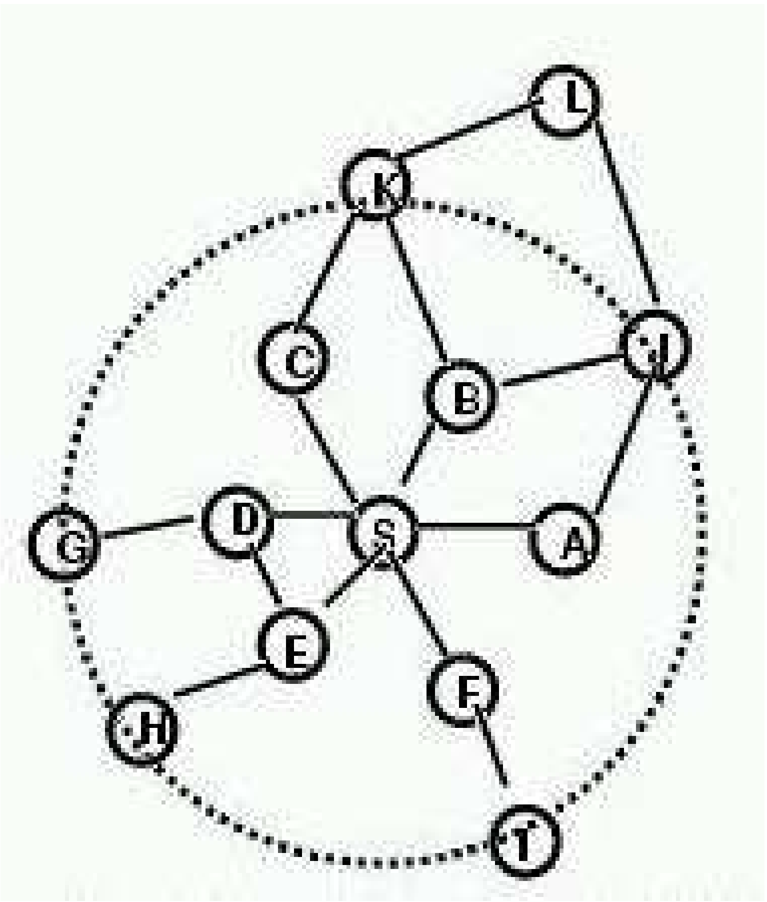
A *routing zone* is defined for each node and includes the nodes whose minimum distance in hops from the node in question is at most some predefined number, which is referred to here as the *zone radius.*



Routing Zone radius of 2 hops

The Notion of Peripheral Nodes

Nodes, whose minimum distance from the node in question is exactly equal to the *zone radius* are referred to as *peripheral nodes.*

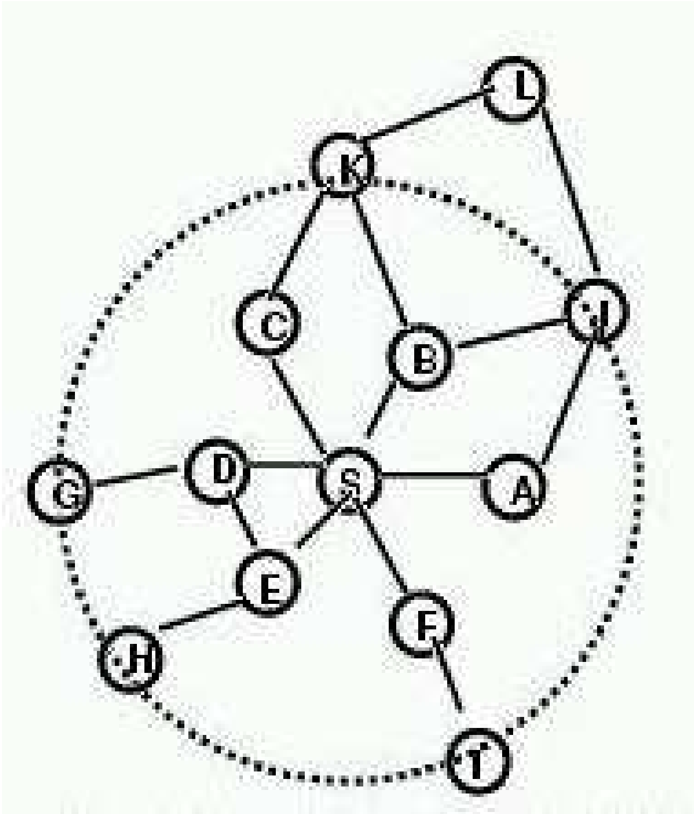


Routing Zone radius of 2 hops

The Zone Routing Protocol (ZRP) (con't)

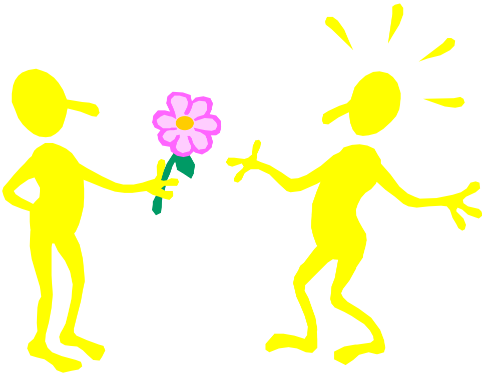
- The source of a query uses *Bordercasting Protocol (BRP)* to deliver messages to the peripheral nodes of its routing zone, if it does not have a route to the destination.

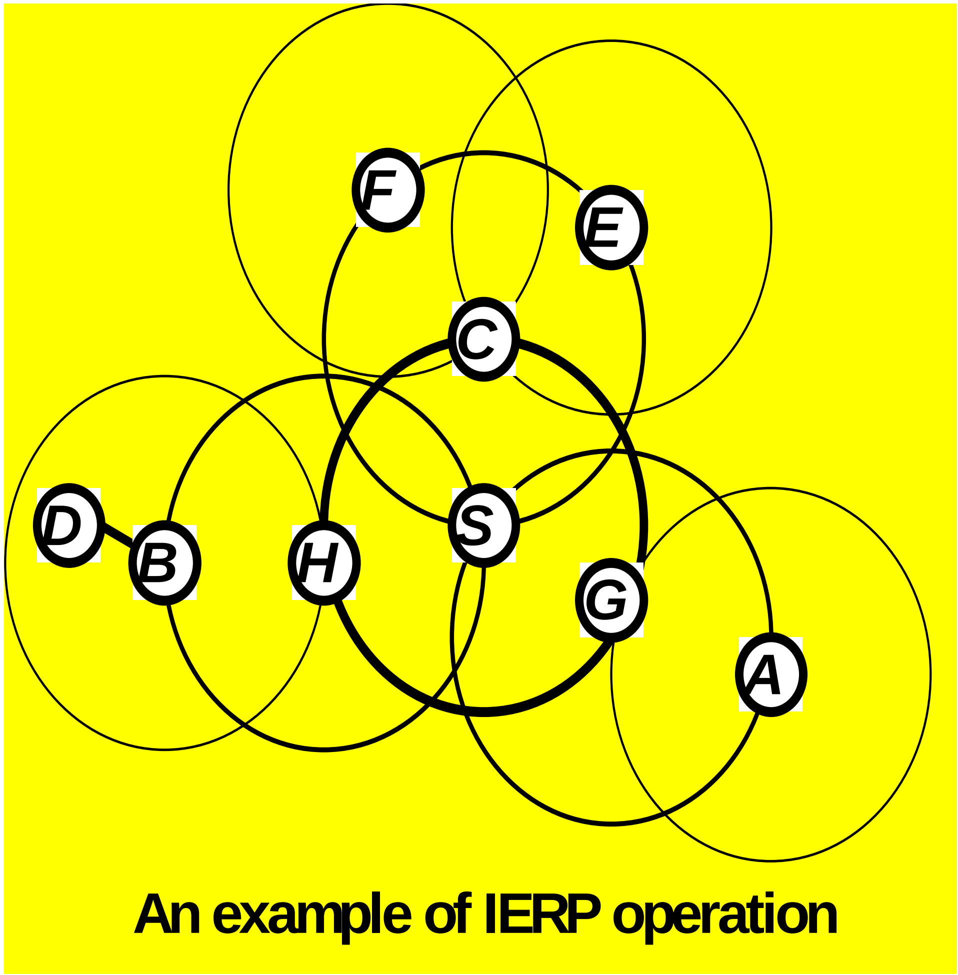
- The peripheral nodes, in turn, *bordercast* the query to their own peripheral nodes if they do not have a route to the destination.



ZRP with routing zone radius 2 hops

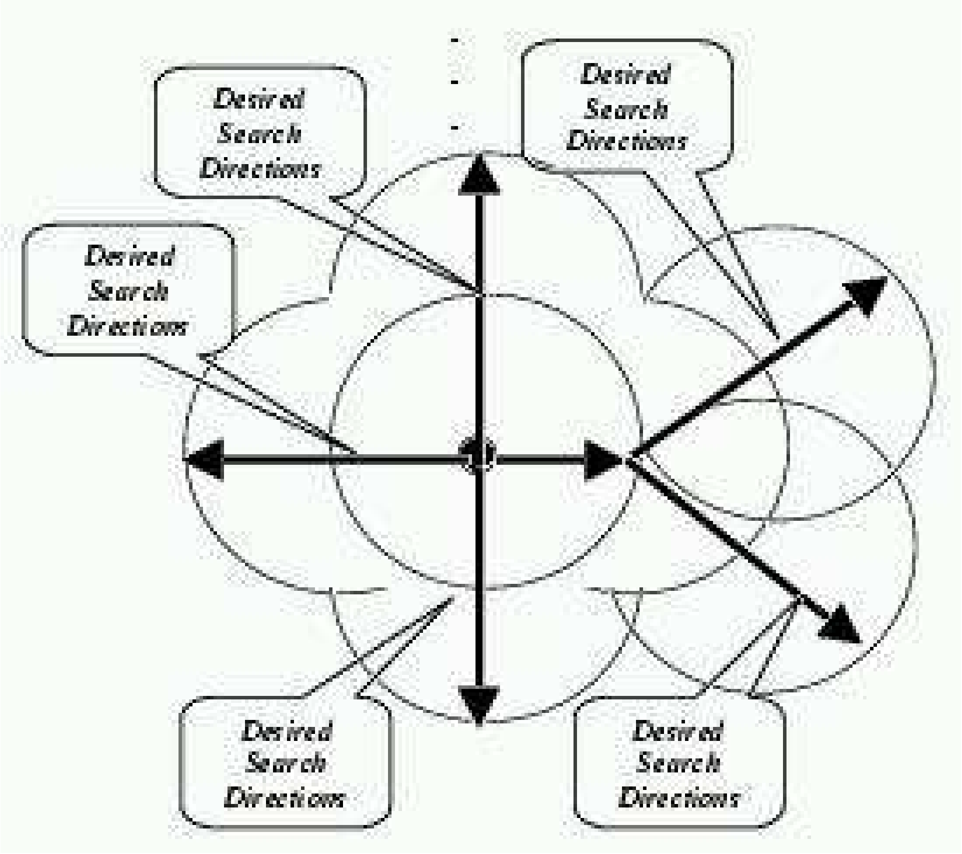
The Operation of the ZRP





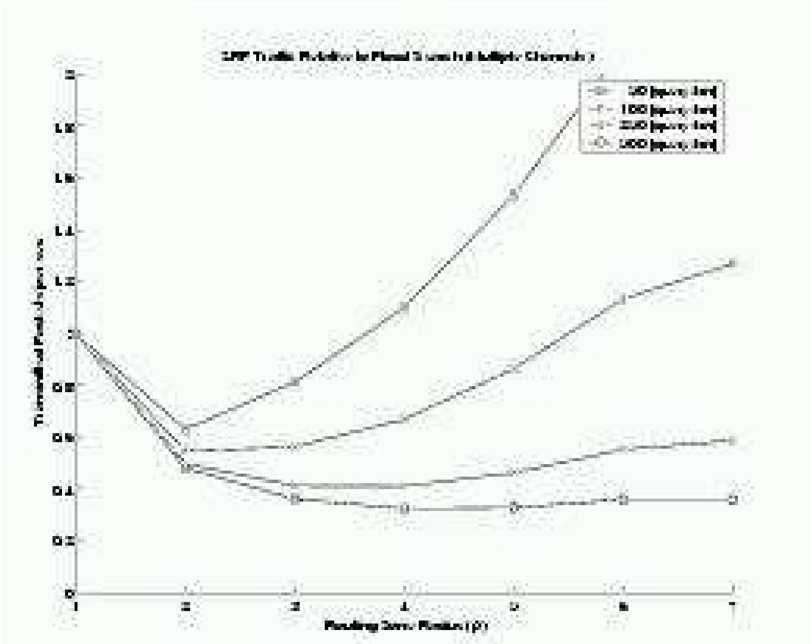
Zone Routing Protocol (ZRP) (con't)

- *Query Detection (QD) & Early Termination (ET)* are used to efficiently query the network, thus reducing the control traffic.

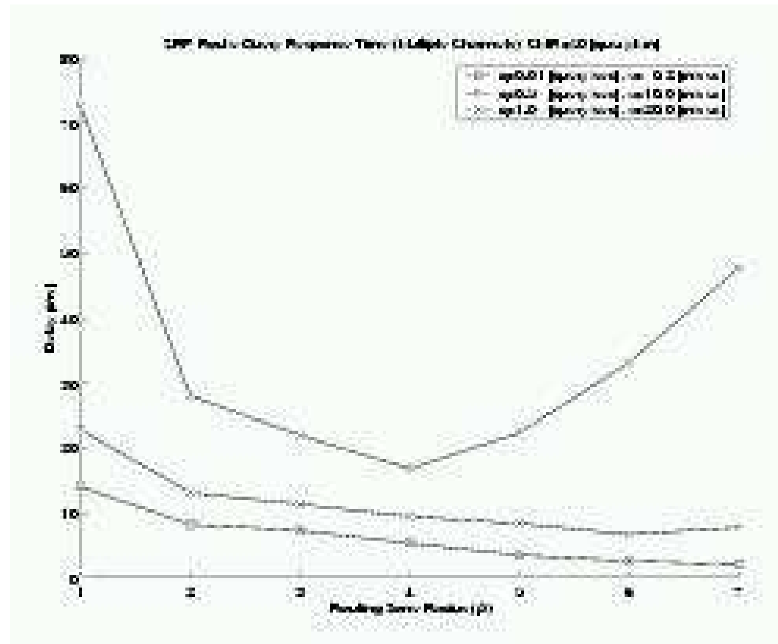


Guiding the search in desirable directions using QD & ET

Some Representative ZRP Performance Results



ZRP traffic relative to flood search vs routing zone radius



ZRP route query response time vs routing zone radius

From ZRP to IZR

- **Zone Routing Protocol (ZRP)**
  - Each node proactively maintains topology information about its *routing zone* - nodes within a constant *zone radius* number of hops.
  - A node reactively queries for routes to destinations lying beyond its routing zone through *bordercasting,* which effectively utilizes the available routing zone topology information.
  - An optimal value of zone radius exists for the network (dependent on average network characteristics) that leads to least routing overhead.
  - All nodes need to be tuned to the same zone radius.
- **Independent Zone Routing (IZR) framework**
  - Nodes have the capability to maintain independently sized routing zones.

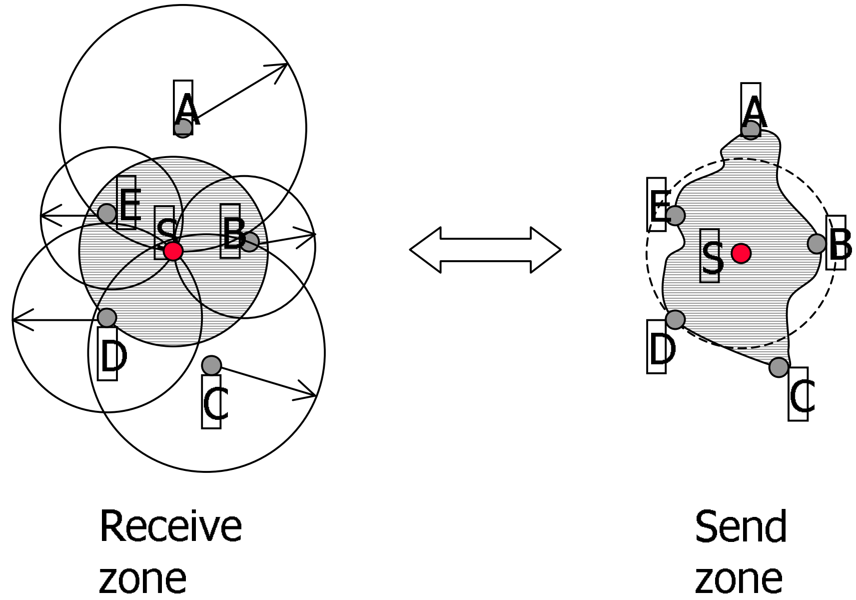
P. Samar, M.R. Pearlman, Z.J. Haas, "Hybrid Routing: The Pursuit of an Adaptable and Scalable Routing Framework for Ad Hoc Networks," Chapter 14, *Handbook of Ad Hoc Wireless Networks*, CRC Press, Dec. 2002.

IZR Properties

- **Different parts of a network may have different characteristics, implying different optimal zone radii.**
  - High mobility and/or low call rates favor smaller zone radius (more reactive routing).
  - Low mobility and/or high call rates favor larger zone radius (more proactive routing).
- **IZR enables each node to independently configure its optimal zone radius in a distributed fashion.**
- **IZR quickly adapts a node's configuration as the local network conditions change.**
- **Allows self organizing network, with nodes free to join or leave at any time, without any external configuration.**

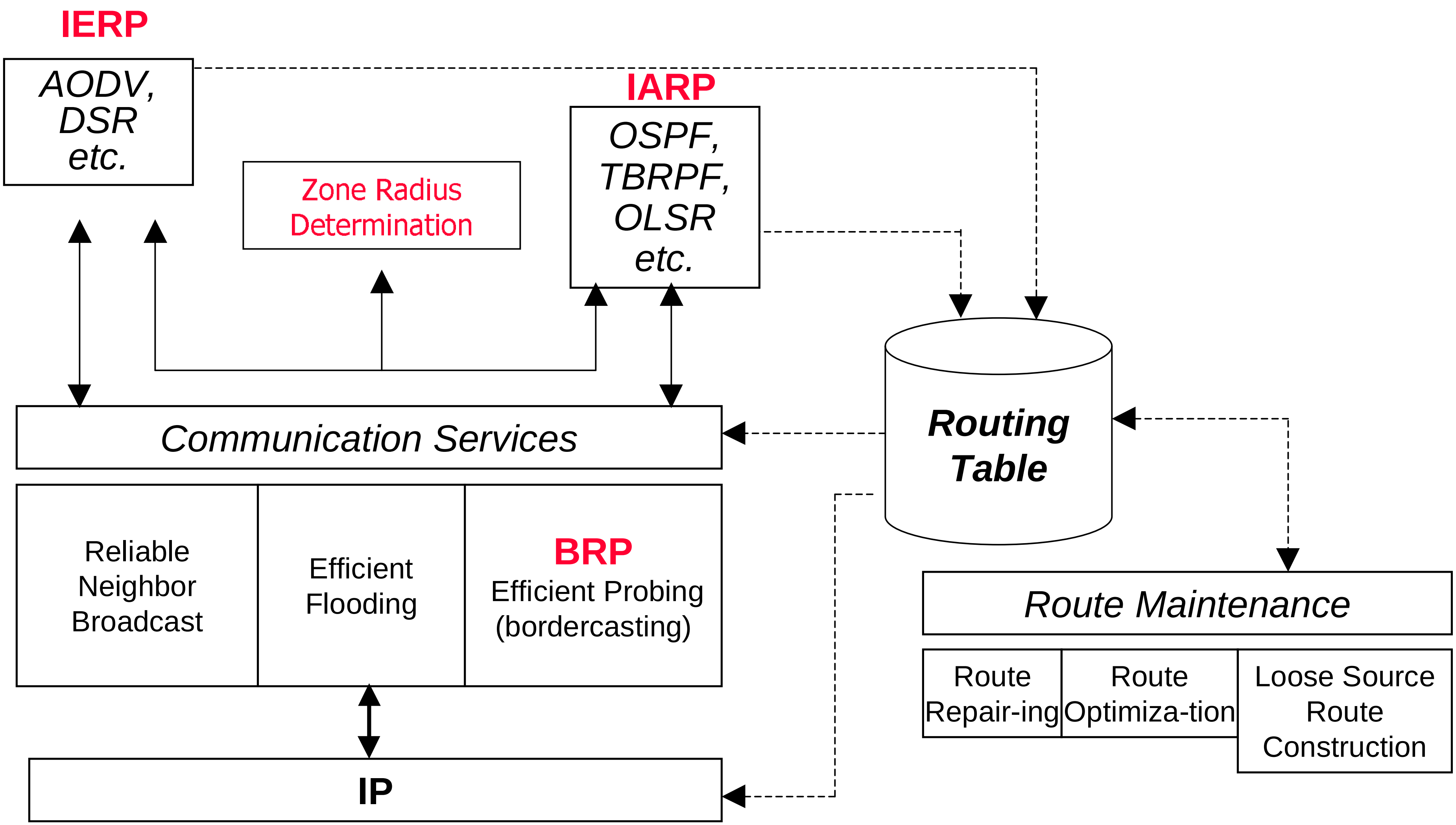
IZR: Overview

- **Independent zone radii imply regular *receive-zones* and not-so-regular *send-zones*.**
- **Intrazone Routing Protocol (IARP) broadcasts a node's proactive updates to its send zone efficiently.**



- **Bordercast Resolution Protocol (BRP) bordercasts the routes queries "outwards" to cover unexplored regions, leveraging the receive zone topology information.**
- **Zone Radius Configuration Algorithm determines the optimal zone radius of *each* node based on local traffic measurements.**

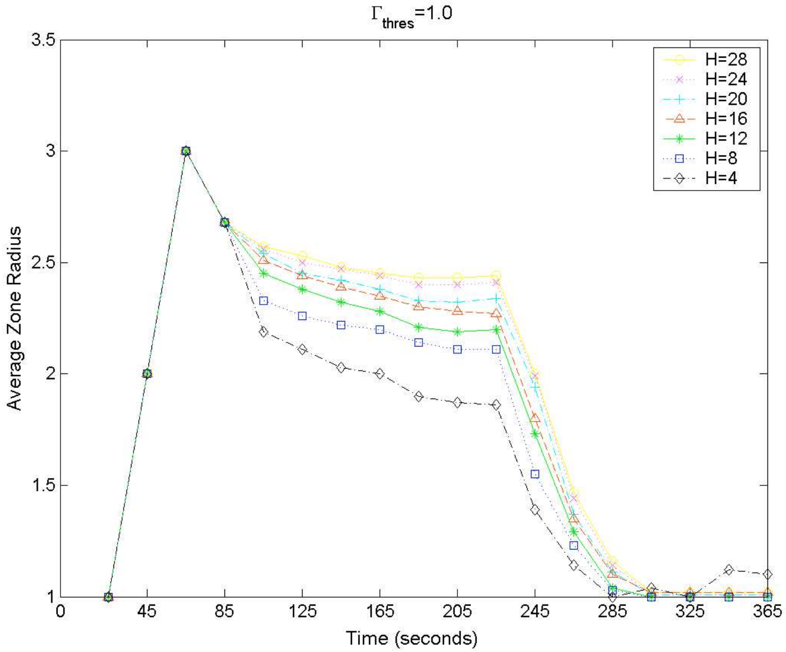
IZR Architecture

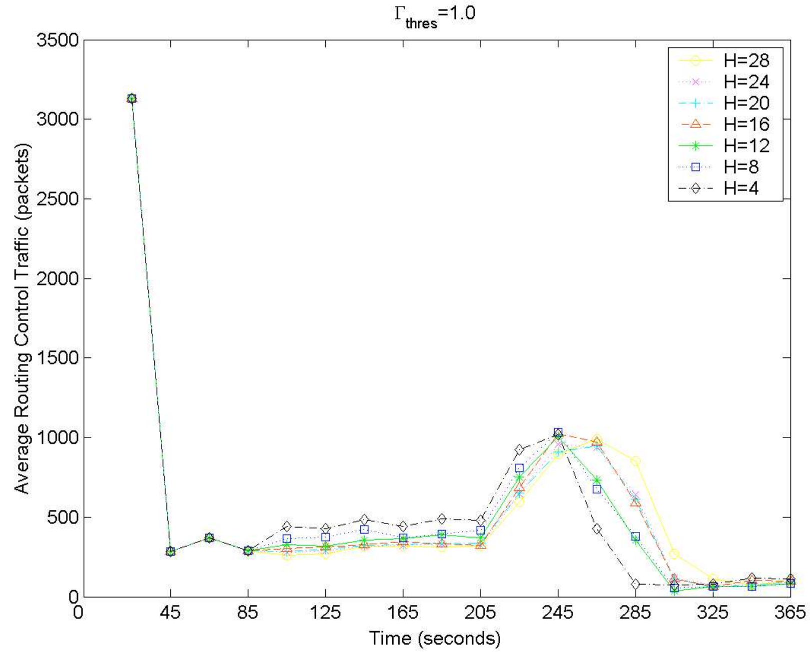


IZR Scalability

- **IZR fine-tunes the framework to the local network characteristics, improving *efficiency*.**
- **IZR *adaptively* reconfigures the framework, making it *robust* to changes in network characteristics with time.**
- ***Hybridization* enables optimal balance of proactive and reactive routing components**
  - Only a subset of network nodes need to be queried
  - Lesser global route queries initiated
- **Adaptivity, efficiency, robustness and hybridization lead to *scalable* routing for ad hoc networks.**

IZR: Performance





- Initially each node moves at a velocity of 0.5 m/sec with call rate 0.33/sec
  - corresponds to optimal zone radius between 2 and 3.
- After 205 seconds, characteristics change to 15 m/sec and 0.005/sec
  - corresponds to optimal zone radius of 1.
- IZR adaptively tracks network changes to reconfigure a node, leading to optimal performance for large size networks ⇒ scalable design