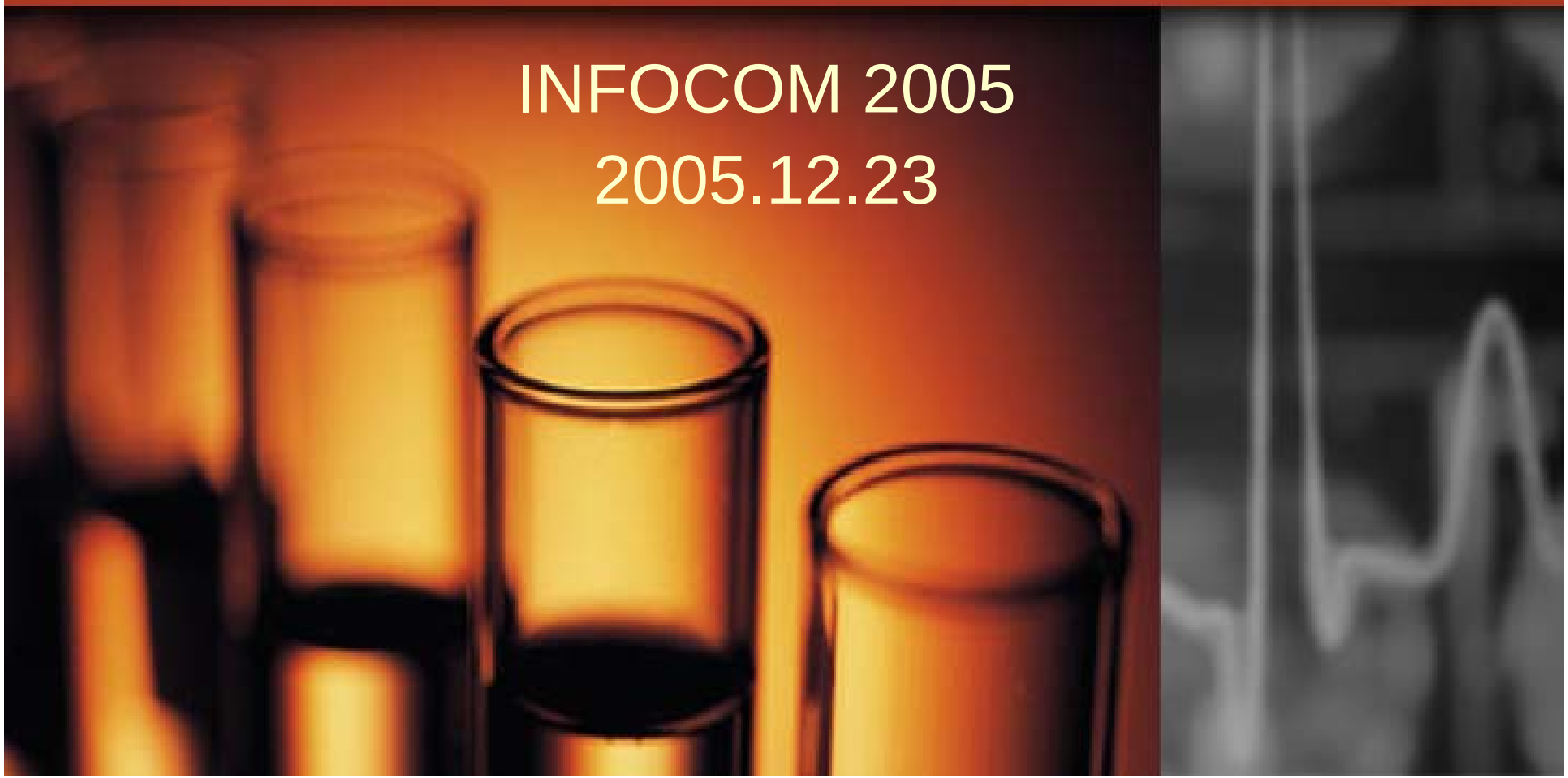
XVR:
X Visiting-pattern Routing for Sensor Networks



INFOCOM 2005

2005.12.23

Outline

- Introduction
- X Visiting-pattern Routing
- Performance Evaluation
- Conclusions and Discussions

Yu He and Cauligi S. Raghavendra, “XVR : X Visiting-pattern Routing for Sensor Networks,” INFOCOM 2005. vol. 3, pp. 1758-1769, Mar. 2005.

Introduction

- Sensor Networks
  - Small, low-cost, and low-power devices
- Routing protocols in sensor networks need to be changed to accommodate application and network dynamics
  - Application: resource discovery, monitoring application
  - Heterogeneous network : different subnets with different routing services

Motivation

- Existing routing services have limited changeability
  - Require re-programming routing function
  - Deployment cost is high
- Many routing services share essential properties but with different visiting-patterns of packets
  - Visiting-pattern: where to forward packets as next hops in a network

Goal

- This paper proposes a general routing service for sensor networks

  “X Visiting-pattern Routing”

  – Facilitates routing changes

Key idea:

--To decouple visiting-patterns of packets from the routing core

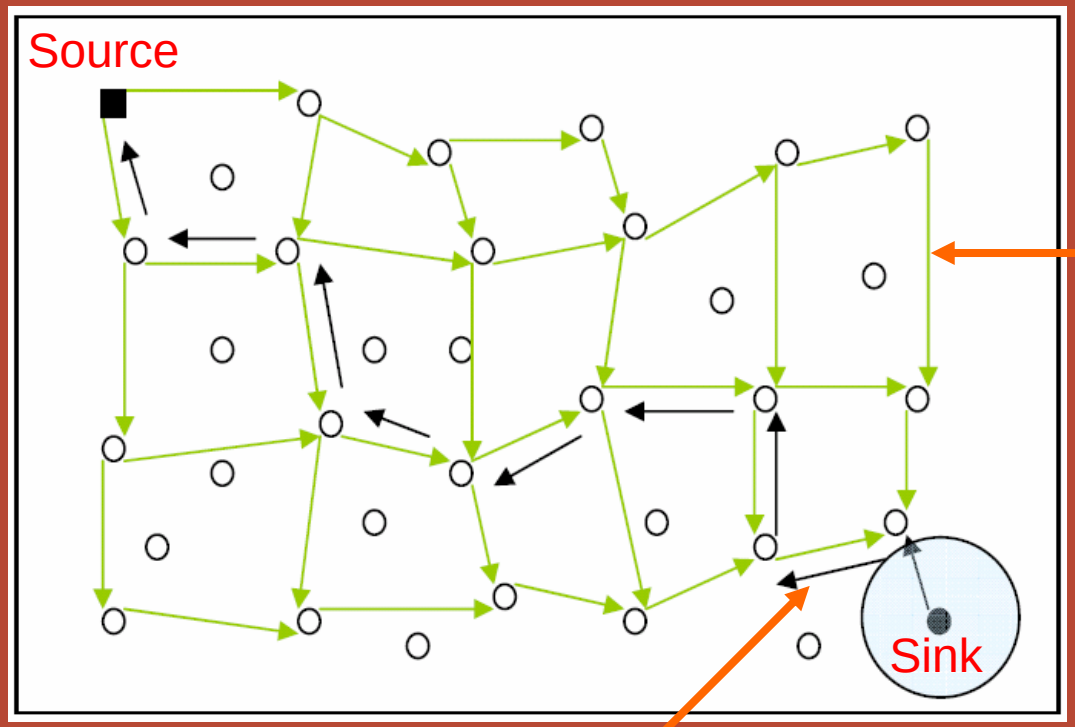
Packet types of a routing service

- Routing Control Packet
  - To help building routes between sources and destinations
    - Its visiting-pattern is associated with routing overhead
- Data Packet
  - Includes data and follows built routes
    - Its visiting-pattern is associated with routing efficiency

Two categories of routing services

- Publication/Subscription-based
  - Sources act as publishing nodes
    - Publishing control packets
  - Sinks act as subscripting nodes
    - Subscripting control packets
- Forwarding-based
  - Packets are directly forwarded based on state information

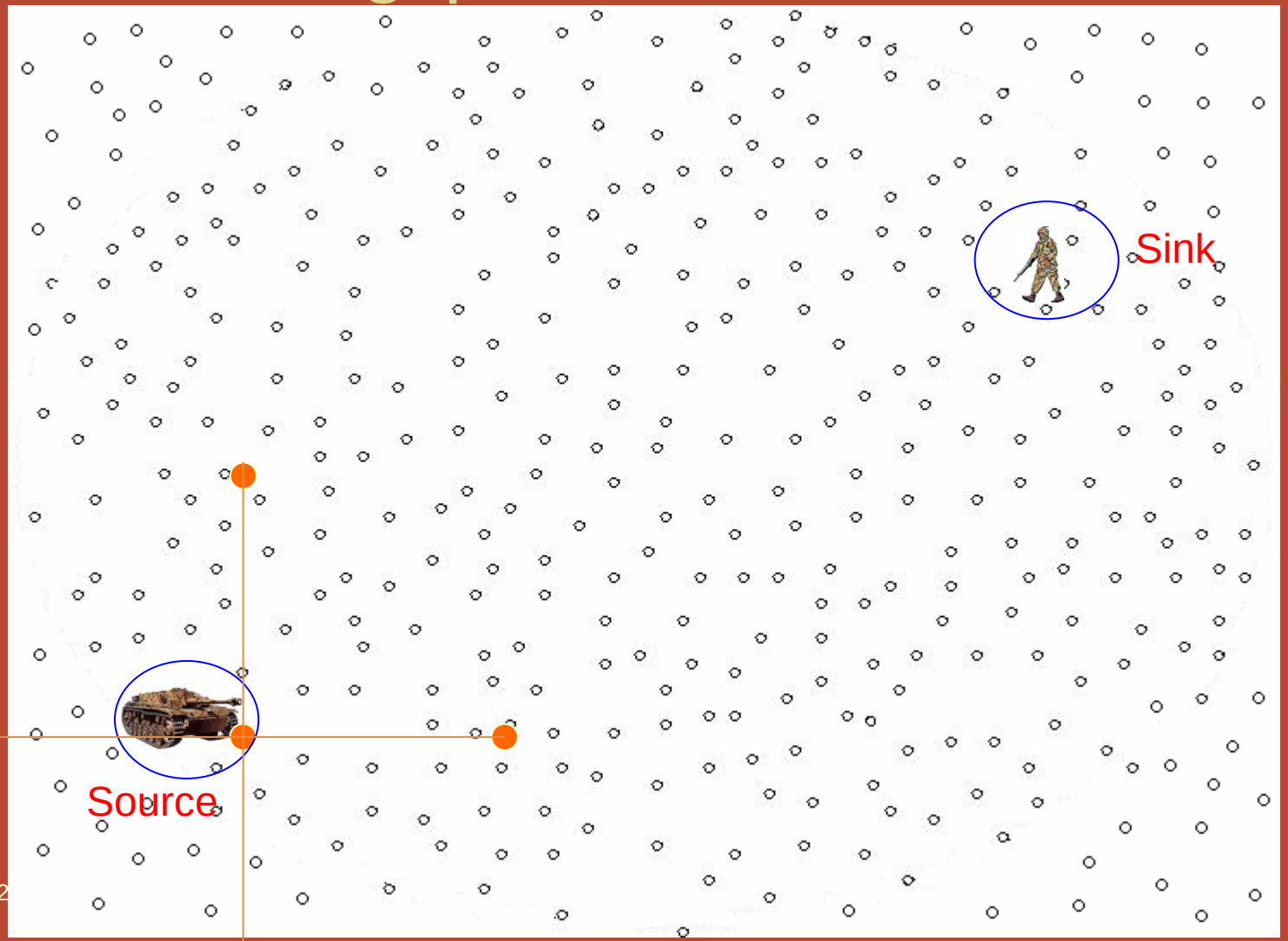
Example -- TTDD



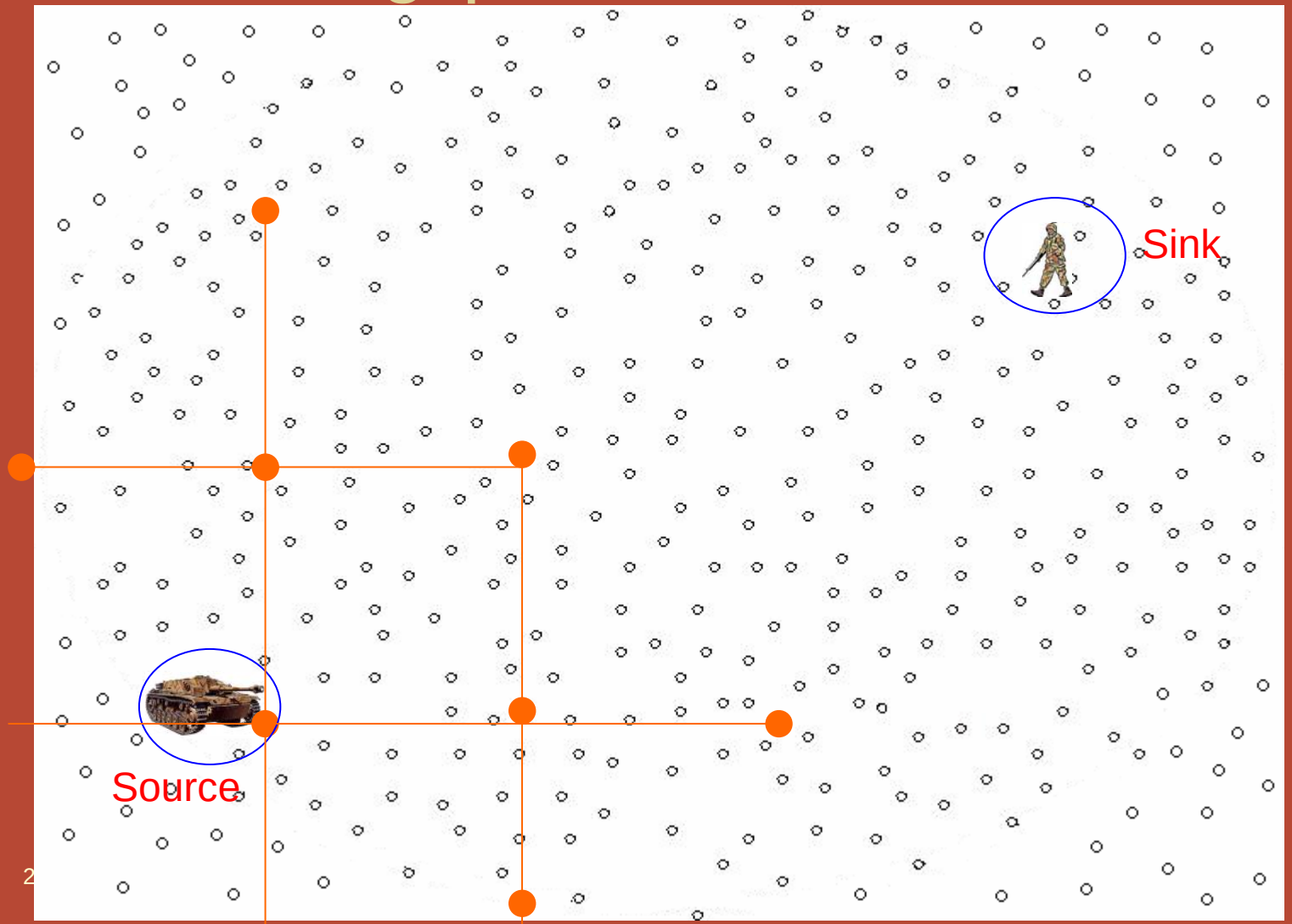
Visiting-pattern of control packets
-- To build path

Visiting-pattern of data packets
-- Next hop selection function

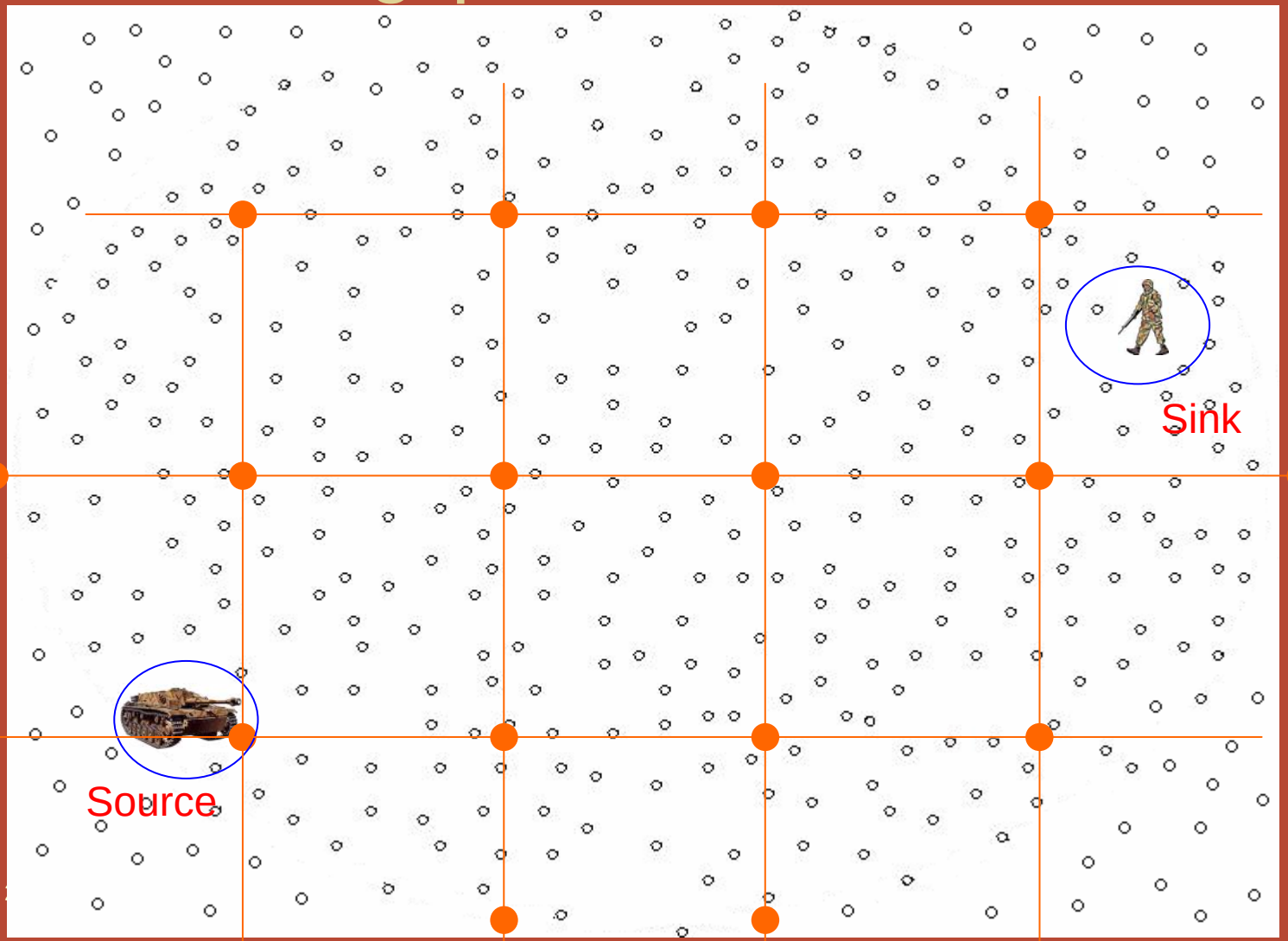
TTDD - Grid construction --building path



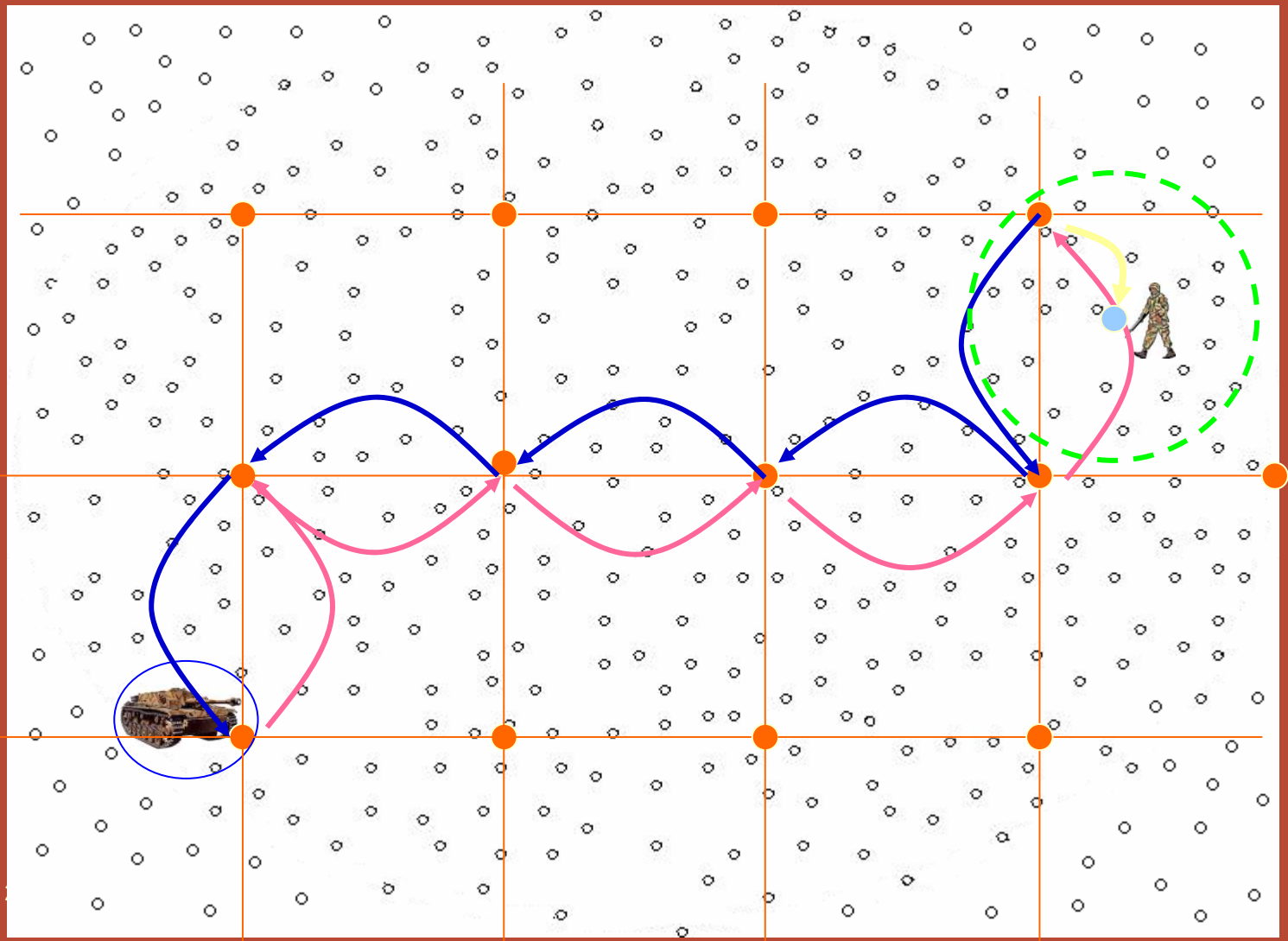
TTDD - Grid construction --building path



TTDD - Grid construction --building path



TTDD - data forwarding



Previous Works

- The existing routing protocols
  - GPSR (Greedy Perimeter Stateless Routing)
  - GEAR (Geographical and Energy Aware Routing)
  - TBF (Trajectory Based Forwarding)
  - Directed diffusion
  - TTDD (Two Tier Data Dissemination)
  - Rumor routing

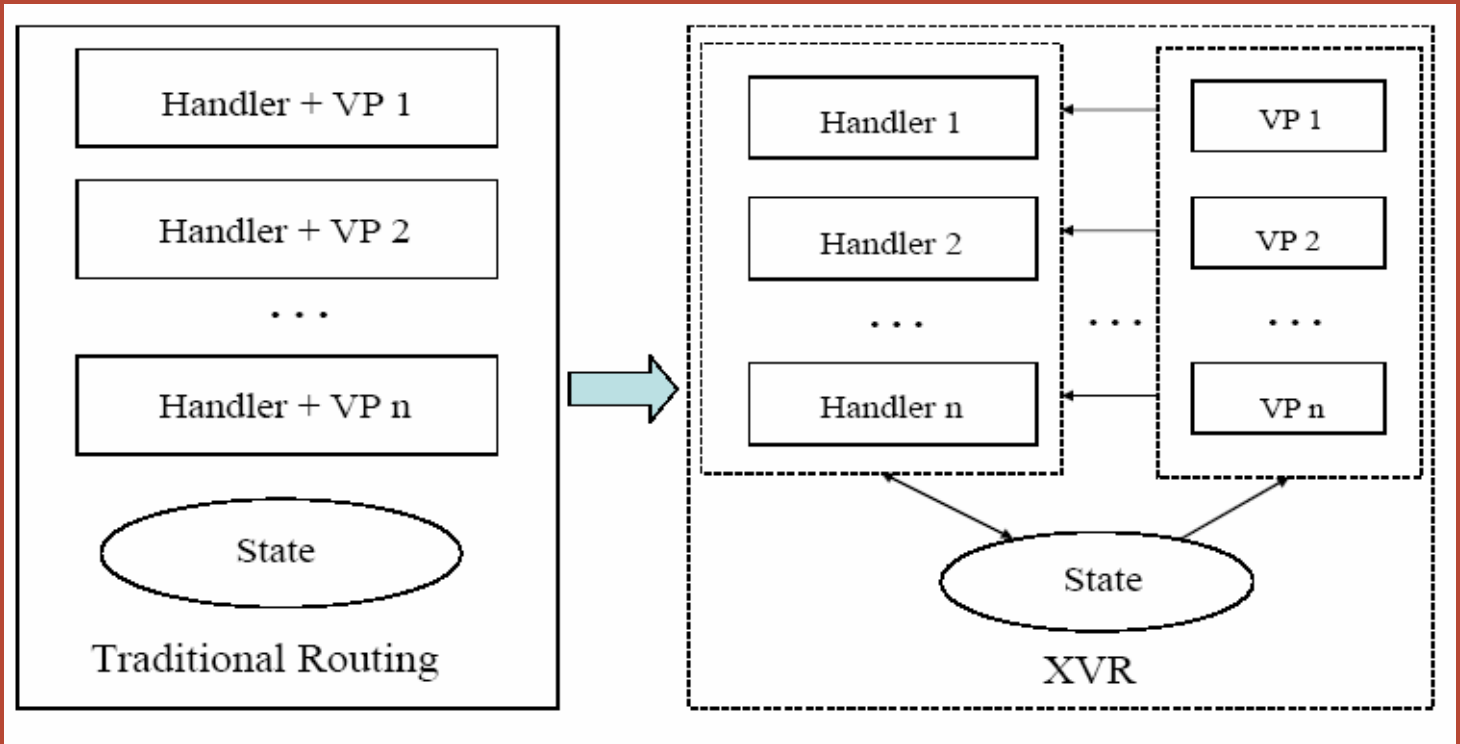
		Next-hop Selection Function
Forwarding-based	GPSR	Closest or perimeter neighbor to destination
	GEAR (GPSR-extension)	Closest to destination areas or multiple neighbors
	TBF	Neighbor along trajectory
Publication/ subscription Based	Directed-diffusion	Interested neighbor
	TTDD	Interested grid cross-point neighbor
	Rumor routing	Next hop in routing state

XVR:
X Visiting-pattern Routing

- Visiting-patterns are a key difference among routing services
- XVR
  - Decouple and parameterize visiting-patterns of packets
- Implementation of XVR
  - The associated packet types
  - Visiting-pattern specifications
  - A collection of state information
  - Visiting-pattern modules

Architecture

- XVR loads the corresponding packet handlers that issue or forward packets according to their visiting-pattern.



Advantages

1. The routing behaviors can be changed without modifying the routing core.
2. Different routing services can be compared in a unified environment.
3. Different visiting-patterns are adaptive to application and network dynamics.

Packet types in the XVR

- Packet types
  - **Subscription** : issued by **sink** to express its interest data
  - **Publication** : issued by **source** to announce data availability
  - **Enforcement** : issued from **source or sink** to build paths
  - **Hello** : issued by **each node** to collect neighbor information
  - **Data** : issued by **source** that includes the actual sensed data

Visiting-pattern in the XVR

- Visiting-patterns (six categories)
  - **Local** : A packet is sent but not out of originator. (static)
  - **Flooding** : From originator to all nodes in a network. (static)
  - **Restricted-flooding** : is the flooding with TTL value. (static)
  - **Probable-forwarding** : To decide if one neighbor will become a next hop with certain probability value. (static)
  - **Geographic-forwarding** : chooses next hop(s) along predefined geographic curves. (static)
  - **Programmable-forwarding** : by consulting state information and packets at service runtime. (dynamic)

Supported visiting-patterns for each packet type in the XVR

	Subscription	Publication
Local	X	X
Flooding	X	X
Restricted-flooding	X	X
Probable-forwarding	X	X
Geographic-forwarding	X	X
Programmable-forwarding	In-code	In-code

Enforcement	Hello	Data
	X	
In-code		In-code or Programmable

State maintained by the XVR

- Three packet types generate states
- Hello
  - Neighbor information state
    - neighbor id, the latest timestamp…etc.
    - XVR dynamically decides what information to be collected from neighbors by checking visiting-pattern parameters.

State maintained by the XVR

- Subscription
  - Interest state
    - Indexed by subscribed attributes and express interest from neighbors about this specified data.
    - Interest state : interested neighbor, latest timestamp, enforced flag
- Publication
  - Available state
    - Indexed by published attributes and express availability from neighbors about the published data.
    - Available state : available neighbor, latest timestamp, enforced flag

Algorithm

- For Publication/subscription-based routing
  - Three algorithm
    - Before-meeting algorithm
    - Meeting algorithm
    - After-meeting algorithm

- Before-meeting algorithm
  - Before a publication (subscription) packet reaches a node with matched interest (available) state, it is forwarded according to its visiting-pattern parameter.
  - Passed nodes build or update available (interest) state that constitutes paths from sources (sinks) to nodes.

Publication packet → interest state
Subscription packet → available state

Algorithm

- Meeting algorithm
  - When a publication (subscription) packet passes a node with matched interest (available) state, one copy of the matched publication packet is made and marked as an *after-meeting packet*.
  - The original publication packet is continuously processed as a *before-meeting packet.*

Algorithm

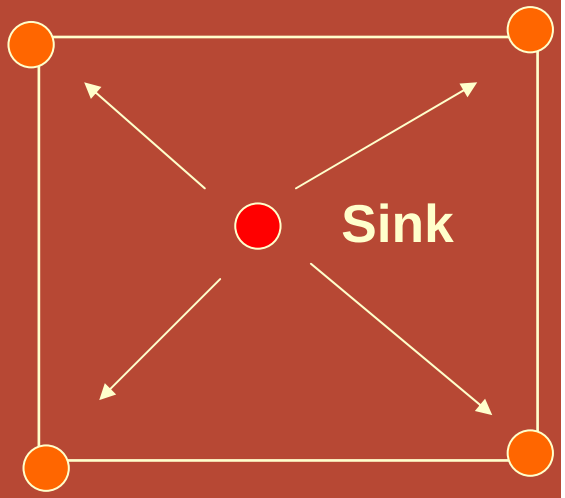
- After-meeting algorithm
  - After-meeting packet don’t follow the specified visiting-pattern parameter.
  - The marked publication (subscription) packets follow paths in interest state to reach sinks (sources)
  - When the publication packets arrive at sinks, enforcement packets are issued from sinks.
  - When the enforcement packets reach sources, route from sources to sink is built.

Using XVR

- To emulate existing routing services

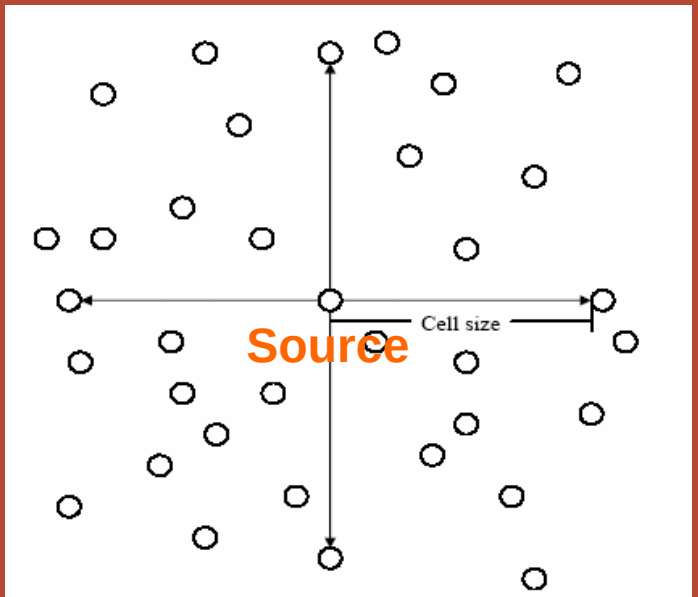
	Subscription	Publication	Hello	Data
GPSR			Restricted-flooding	Programmable-forwarding
GEAR			Restricted-flooding	Programmable-forwarding
TBF			Restricted-flooding	Programmable-forwarding
2pp-Diffusion	Flooding	Local		
Push-Diffusion	Local	Flooding		
1pp-Diffusion	Flooding	Local		
TTDD	Restricted-flooding	Geographic-forwarding	Restricted-flooding	
Rumor-routing	Probable-forwarding	Probable-forwarding	Restricted-flooding	

Using XVR--Example



For TTDD

- Subscription visiting-pattern
  - Restricted-flooding
- Publication visiting-pattern
  - Geographical-forwarding
    - To build grid structure throughout the network



Starting-angle = 0
Step-angle = 90
Number = 4
Distance = cell size

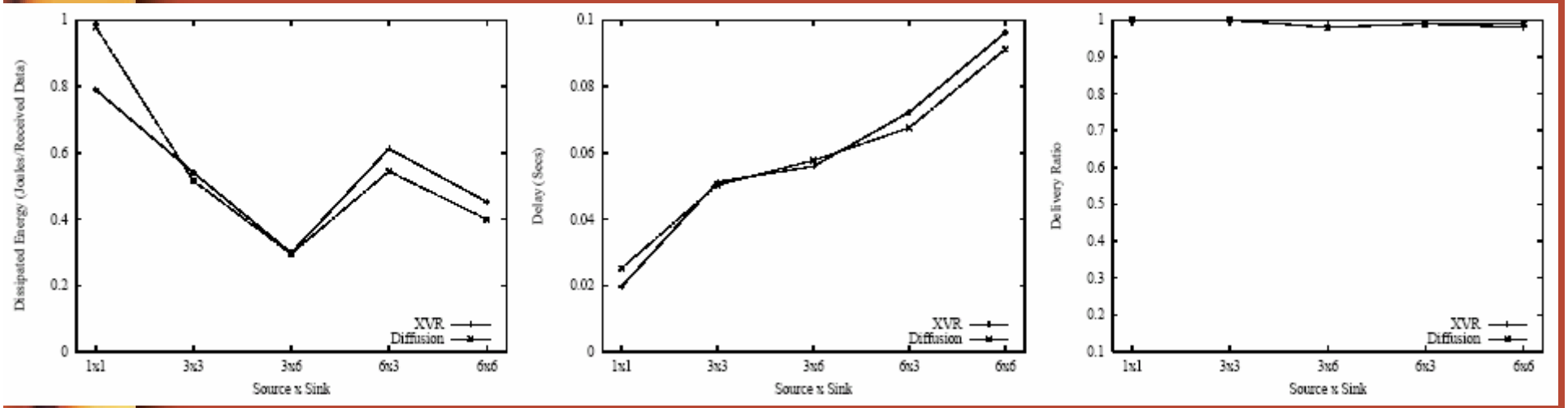
Performance Evaluation

- XVR is implemented in ns-2
- 100 nodes in 1500m * 1500m
- # of sinks and sources = 1, 3, 6
- Sending rate = 2 secs/packet
- Publication/Subscription packet size = 88 bytes
- Enforcement packet size = 104 bytes
- Data packet sizes = 106 bytes
- Hello packet sizes = variable lengths (depend on VP)
- Simulation time = 200 secs

- Simulation Metric
  - Dissipated Energy ratio
  - Delay
  - Delivery ratio

Simulation result

- XVR vs. Directed Diffusion

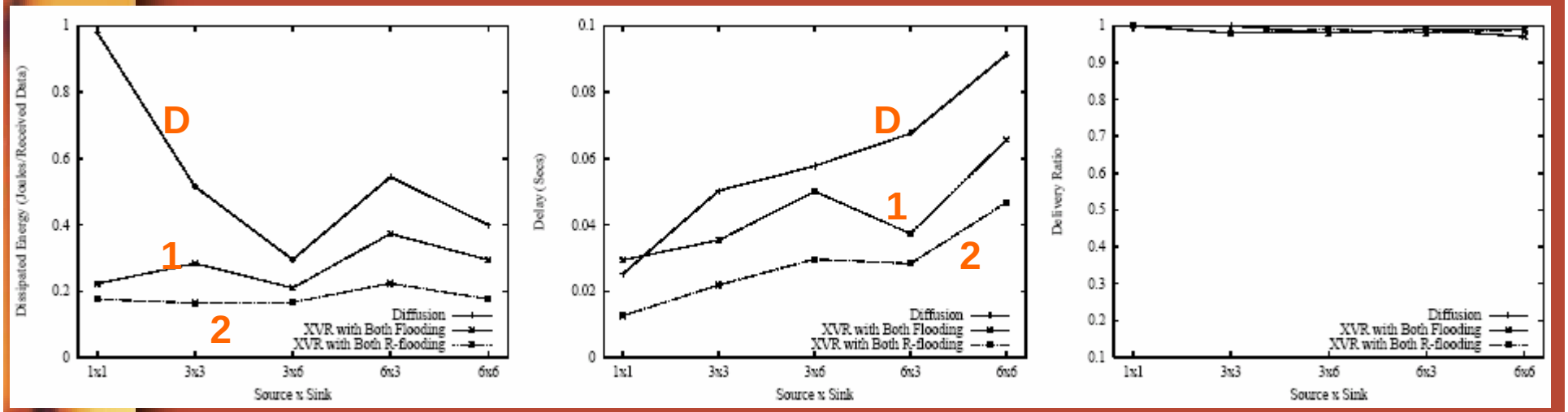


Dissipated Energy ratio **Delay** **Delivery ratio**

Visiting-pattern
Subscription (sink): Flooding
Publication (source): Local

Simulation result

- New Routing services vs. Directed Diffusion



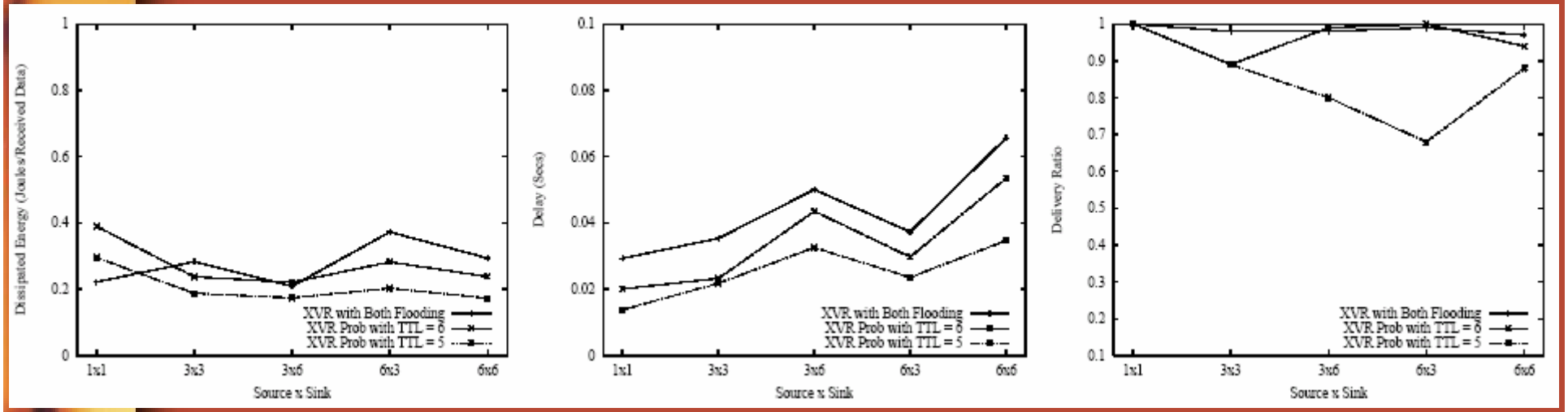
Dissipated Energy ratio **Delay** **Delivery ratio**

New Visiting-pattern 1
Subscription (sink): Flooding
Publication (source): Flooding

New Visiting-pattern 2
Subscription (sink): R-Flooding
Publication (source): R-Flooding

Simulation result

- New Routing service1 vs. Probable visiting-pattern

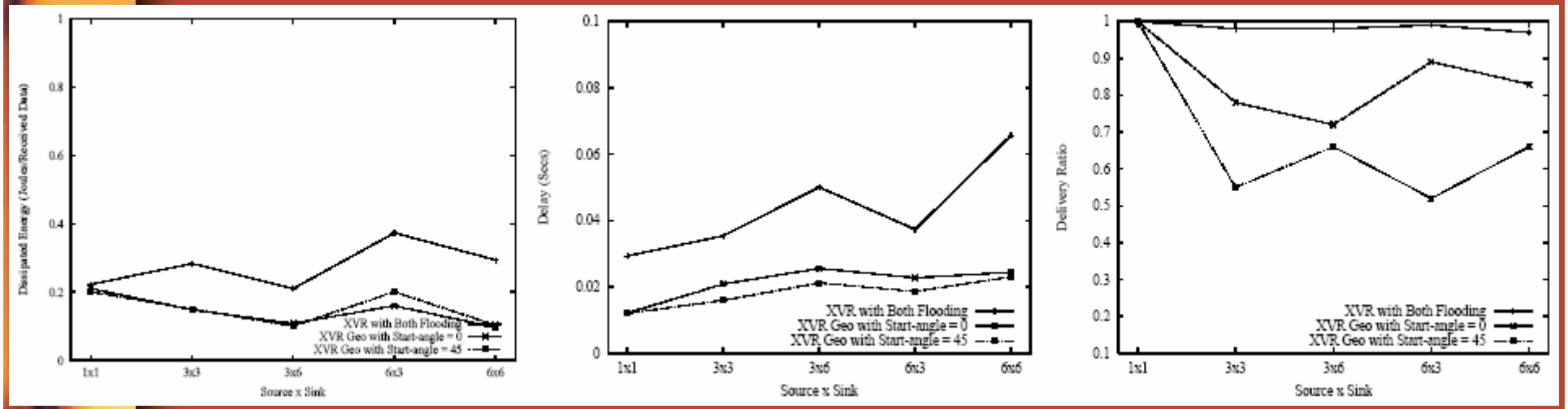


Dissipated Energy ratio **Delay** **Delivery ratio**

Probable visiting-pattern
Subscription (sink): R-Flooding (TTL = 5, 6)
Publication (source): Randomly choose neighbors to forward packets (50%)

Simulation result

- New Routing service1 vs. Geographic forwarding visiting-pattern (TTDD)



Dissipated Energy ratio **Delay** **Delivery ratio**

Geographic forwarding visiting-pattern
Subscription (sink): send in 4 straight lines along certain angle (starting angle = 0, 45) (step angle = 90)
Publication (source): R-Flooding (TTL = 5)

Conclusions

- This paper proposes a general routing service for sensor networks.
- Routing overhead can be reduced by changing the visiting-pattern parameters.
- Experiments with XVR can answer some research questions
  - Which routing algorithm performs best under what application and network condition.

Discussions

- XVR for forwarding-based routing services is not done.
- XVR is not fit for sensor networks
  - Control packets are too big
- We can use XVR as our testing platform to find which routing algorithm is suitable for our projects.
- Research topic:
  - Automatic and concurrent routing protocols in heterogeneous networks.