End-to-End Reliable Event Transfer in Wireless Sensor Networks

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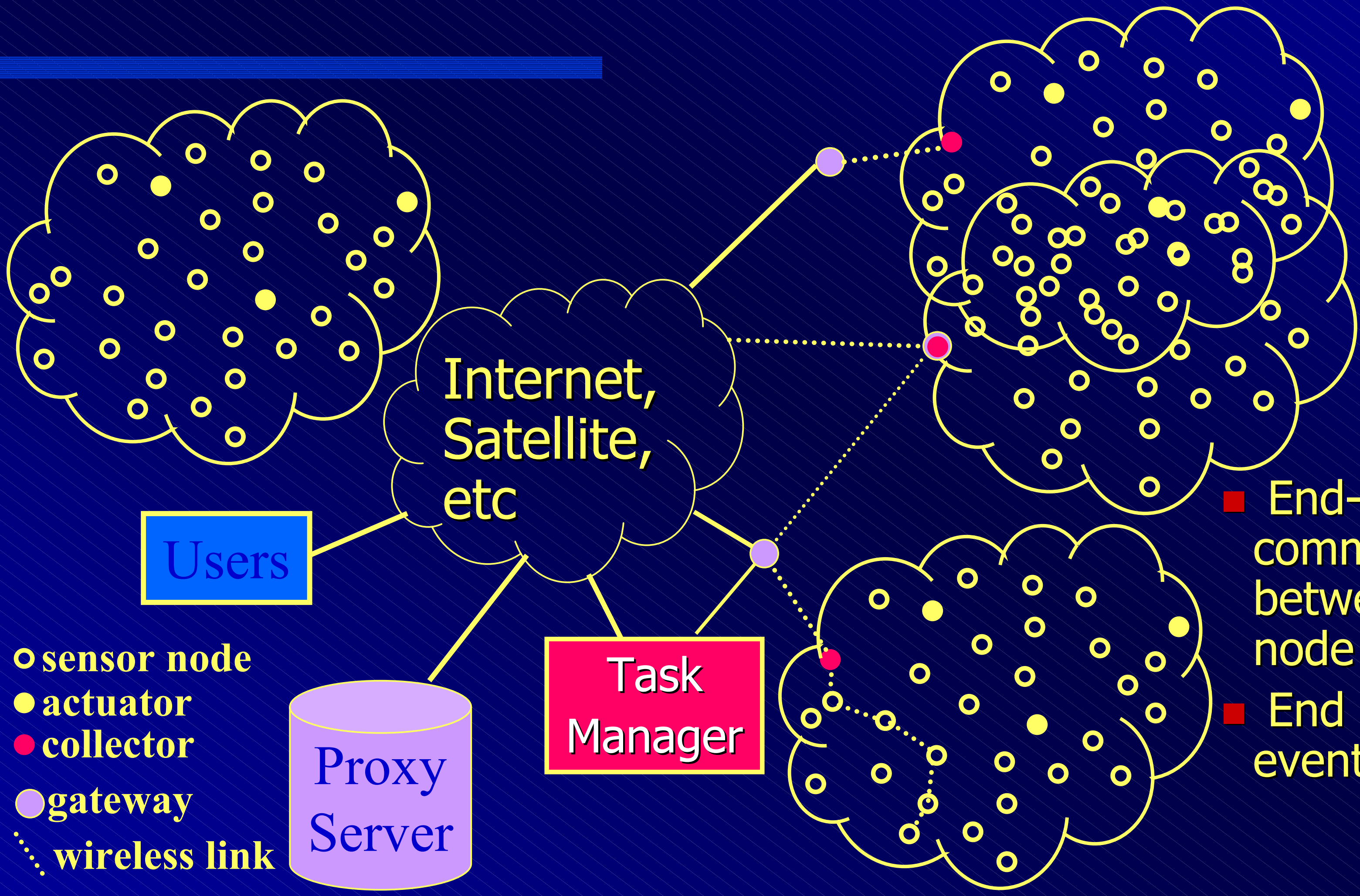
Outline

- Introduction and related work
- End-to-end event reliability
- Schemes not based on acknowledgements
- Schemes based on acknowledgements
- Conclusion

Transport Layer



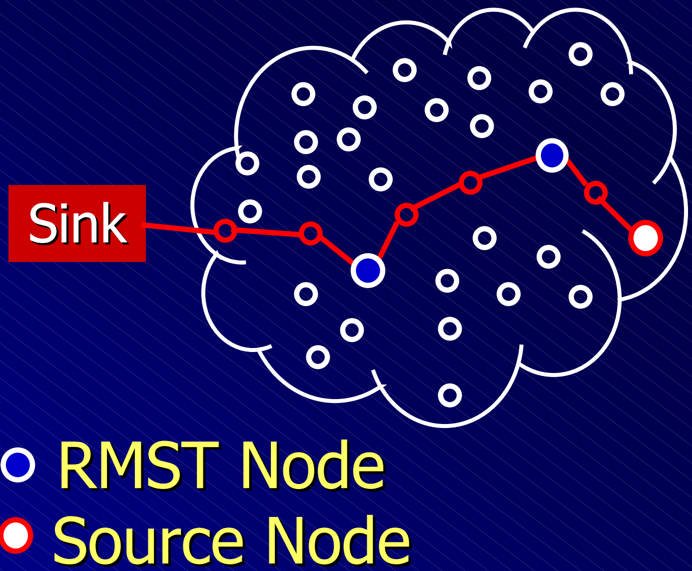
- End-to-end communication between a sensor node and a user,
- End to end reliable event transfer,

Reliable Multi-Segment Transport (RMST)

(F. Stann, J.Wagner, “RMST: Reliable Data Transport in Sensor Networks,” *SNPA 2003*)

- RMST is a transport layer protocol for directed diffusion.
- RMST provides end-to-end data-packet transfer reliability.
- RMST is a selective NACK-based protocol that can be configured for in-network caching and repair.
- There are two modes for RMST: caching mode, non-caching mode.
- In caching mode, a number of nodes along a reinforced path, path being used to convey the data to the sink by directed diffusion, are assigned as RMST nodes.

Reliable Multi-Segment Transport (RMST)



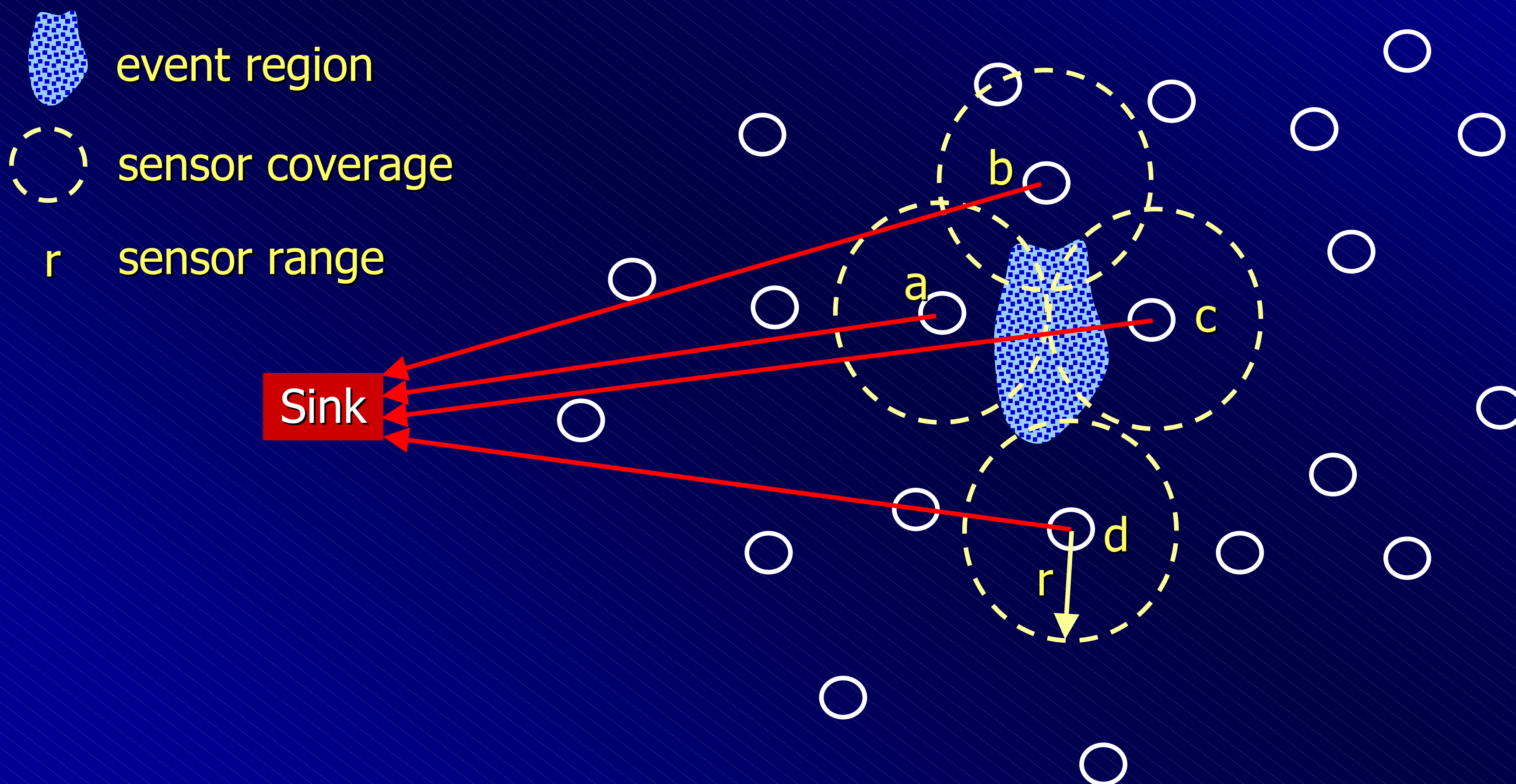
- Each RMST node caches the fragments identified by FragNo of a flow identified by RmstNo.
- Watchdog timers are maintained for each flow. When a fragment is not received before the timer expires, a negative acknowledgement is sent backward in the reinforced path.
- The first RMST node that has the required fragment along the path retransmits the fragment.
- Sink acts as the last RMST node. In non-caching mode, sink is the only RMST node.
- RMST relies on directed diffusion scheme for recovery from the failed reinforced paths.

Pump Slowly Fetch Quickly (PSFQ)

(C-Y Wan, A.T. Campbell, L. Krishnamurty, "PSFQ: A Reliable Transport Protocol for Wireless Sensor Networks," W*SNA'02*)

- PSFQ comprises three functions: message relaying (pump operation), relay initiated error recovery (fetch operation) and selective status reporting (report operation).
- Every intermediate node maintains a data cache.
- A node that receives a packet check its content against its local cache, and discards any duplicates.
- If the received packet is new, the TTL field in the packet is decremented.
- If the TTL field is higher than 0 after being decremented, and there is no gap in the packet sequence numbers, the packet is scheduled to be forwarded.
- The packets are delayed a random period between Tmin and Tmax, and then relayed.
- A node goes to fetch mode once a sequence number gap is detected.
- The node in fetch mode requests a retransmission from neighboring nodes.

End-to-end Reliable Event Transfer



End-to-end Reliable Event Transfer

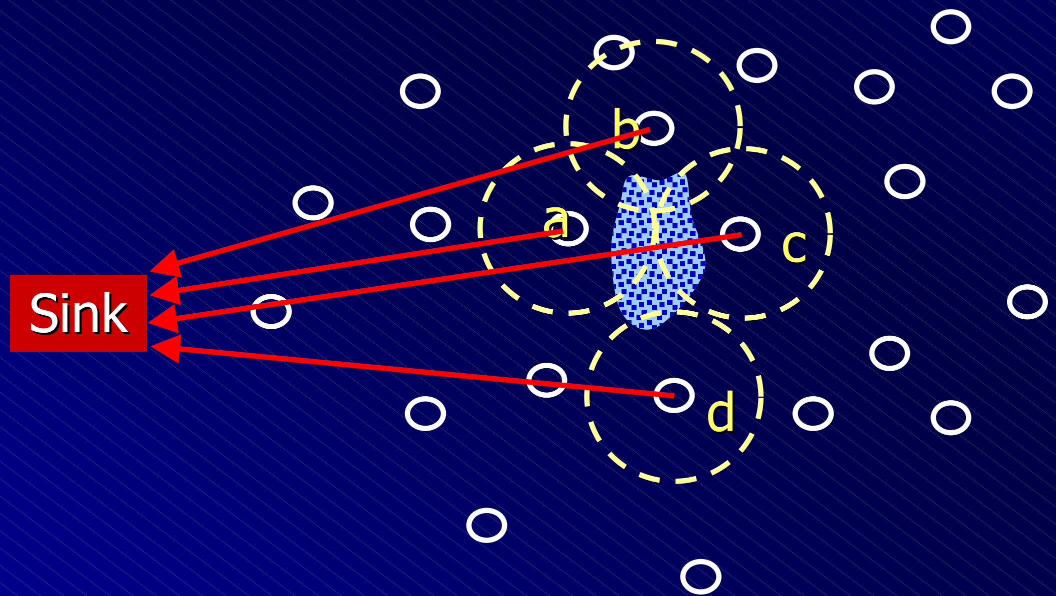
1. Schemes not based on acknowledgements
   a. Frequency based
   b. Density based

2. Schemes based on acknowledgements
   a. Selective acknowledgements
   b. Enforced acknowledgements
   c. Blanket acknowledgements

Event-to-Sink Reliable Transport (ESRT)

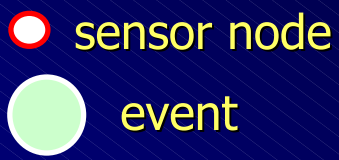
(Y. Sankarasubramaniam, O.B. Akan, I.F. Akyildiz, “ESRT: Event-to-Sink Reliable Transport in Wireless Sensor Networks,” Mobihoc’03)

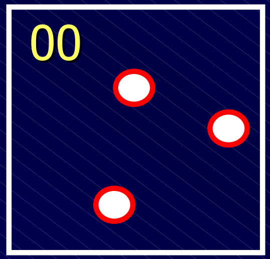
- ESRT is the first scheme that focuses on the end-to-end reliable event transfer.
- The end-to-end event transfer reliability is controlled based on the reporting frequencies of sensor nodes.



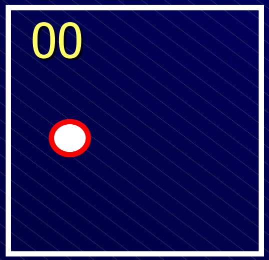
Task Sets

C. Cimen, E. Cayirci, V. Coskun, "Querying Sensor Fields By Using Quadtree Based Dynamic Clusters and Task Sets," Proc. of the MILCOM 2003.

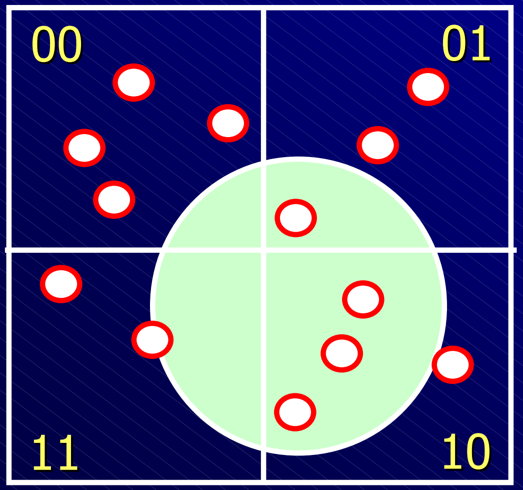




Task Set 2

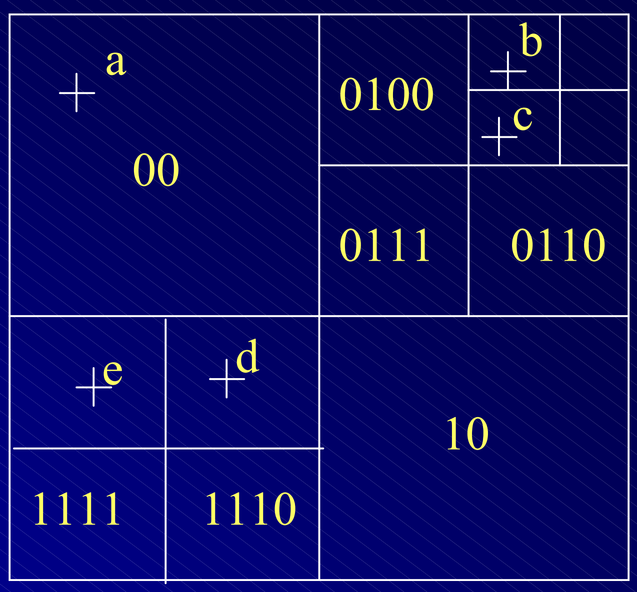


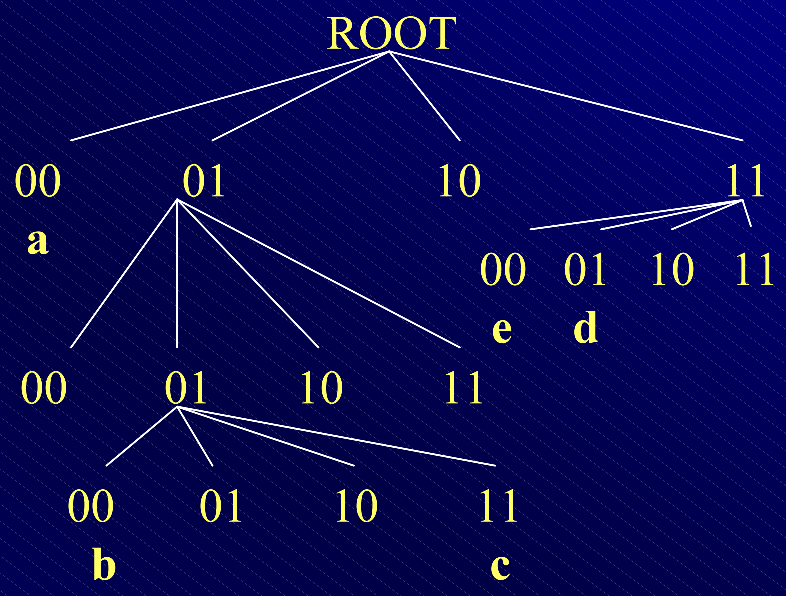
Task Set 1



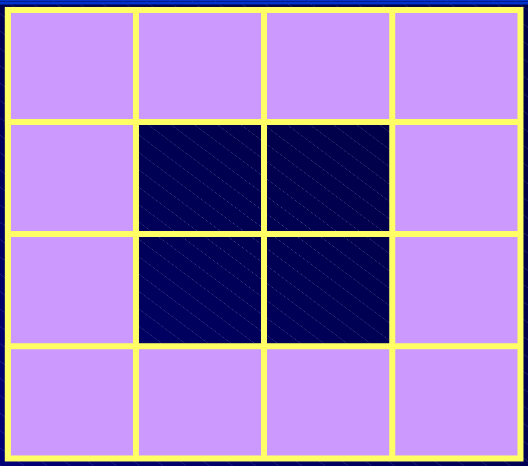
Quadtree Address	Sensor Type	Power Available	Task Set
00	1	0.95	2
00	1	0.98	1
00	1	0.93	2
00	1	0.96	2

Quadtree/Octree Addressing

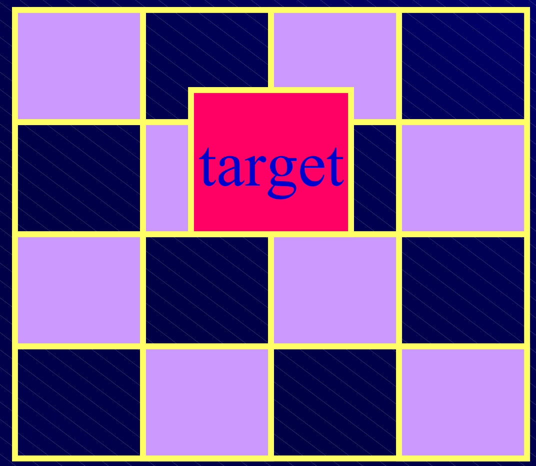




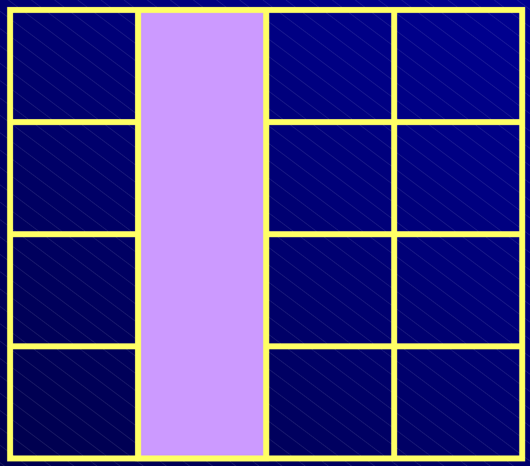
Quadtree/Octree Addressing



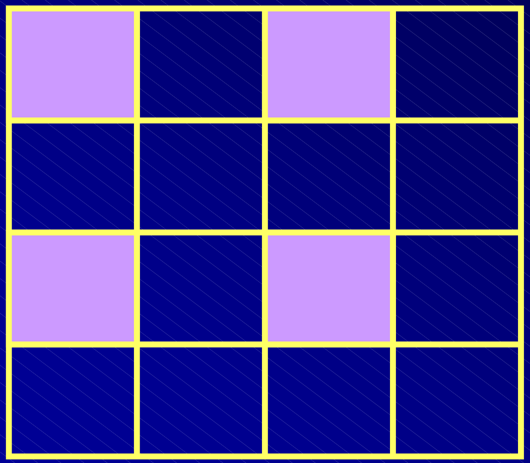
0*0* + 1*1* + *1*0 + *0*1



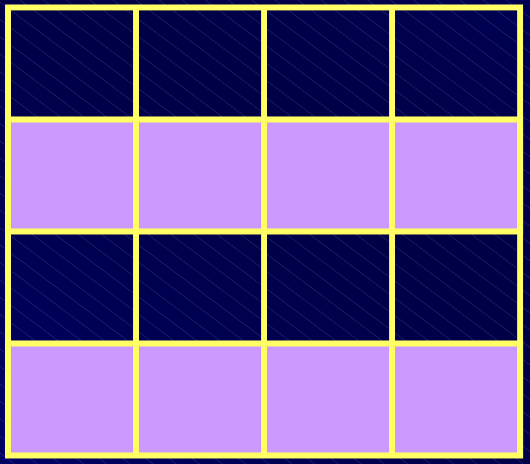
***0



0001 + 0010 + 1101 + 1110

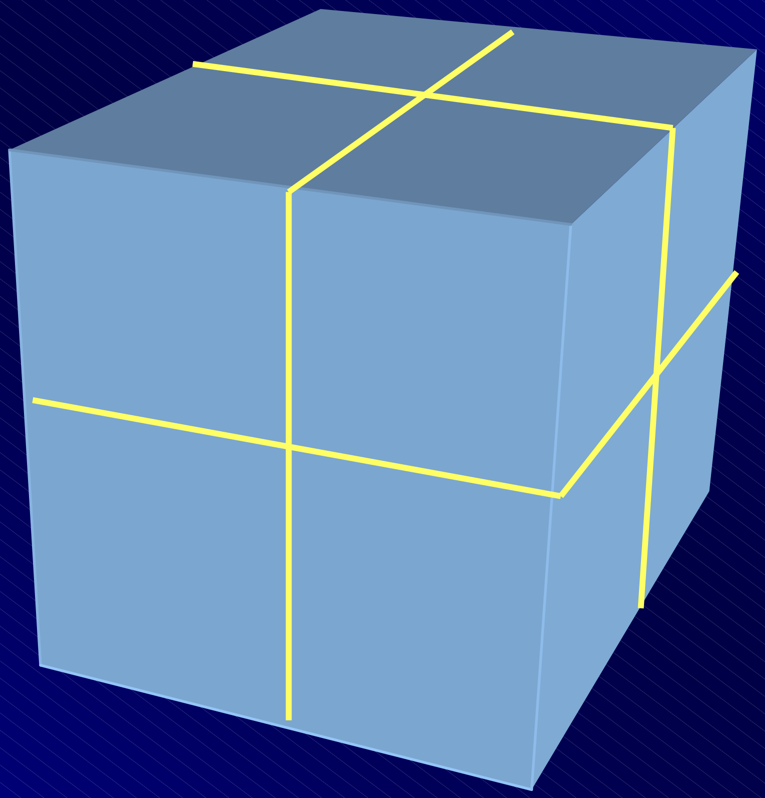


**00
(higher left quadrants at level 2)



**1*
(lower quadrants at level 2)

Quadtree/Octree Addressing



Data Aggregation and Dilution by Modulus Addressing

E. Cayirci, "Data Aggregation and Dilution by Modulus Addressing in Wireless Sensor Networks," IEEE Communications Letters, August 2003.

$$f(x) = x \; div \; m \qquad (1)$$

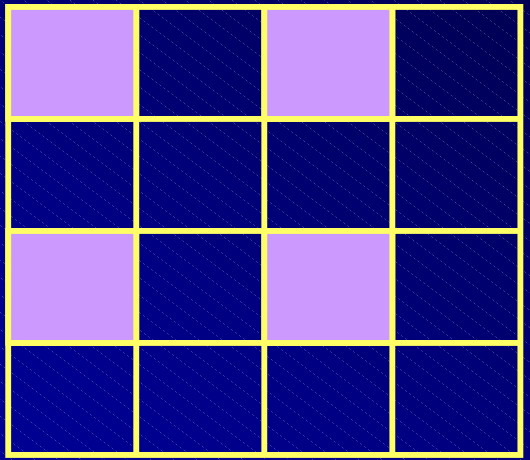
$$f(x) = (x / r) \bmod (m / r) \qquad (2)$$

where

x **is the grid location of a node relative to one of the axes,**

r **is the resolution in meters, and**

m **is the dilution or aggregation factor.**



Select [task, time, location, [distinct | all], amplitude,
[[avg | min |max | count | sum] (amplitude)]]

from [any , every , aggregate *m* , dilute *m*]

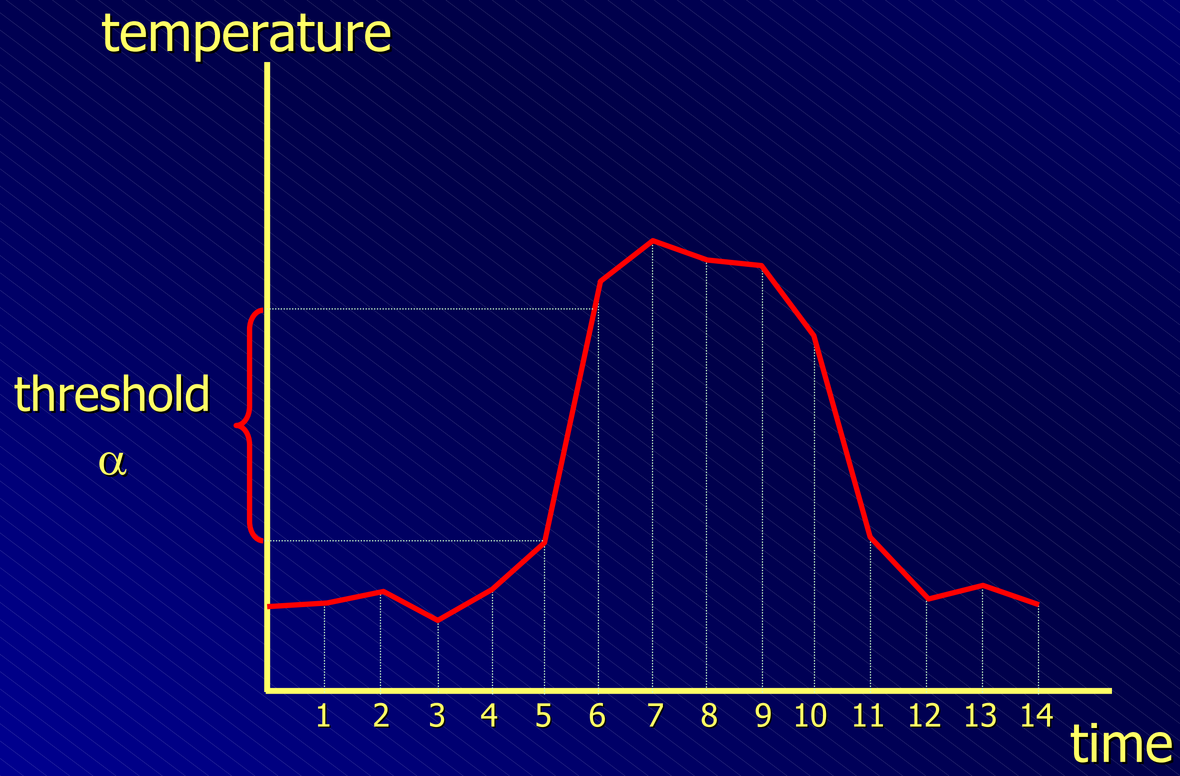
where [power available [<|>] *PA* |
location [in | not in] *RECT* |
t_{min} < time < t_{max} |
task = *t* |
amplitude [<|==|>] *a*]

group by task

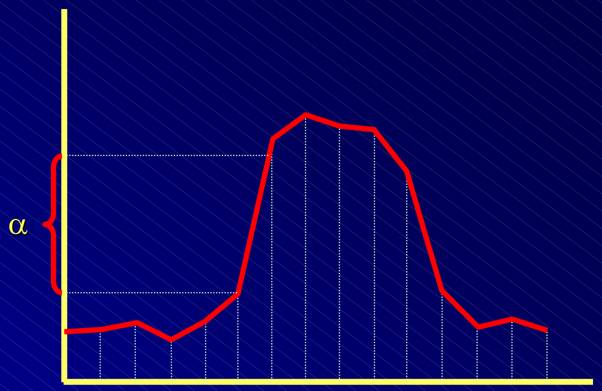
based on [time limit = l_t | packet limit = l_p |
resolution = *r* | region = *xy*]

End-to-end Acknowledgements for Events

N.Tezcan, E. Cayirci, U. Caglayan, "End-to-end reliable event transfer in wireless sensor networks," submitted to PIMRC 2004.



Selective Acknowledgements



- Both ends know the threshold.
- When the receiver finds out that the difference between the value in a new sensed data packet and in the previous packet is higher than the threshold, this indicates a critical data packet, and it acknowledges the receipt of the critical packet.
- If the sender does not receive an acknowledgement for a critical packet during the timeout period, it retransmits the critical packet.

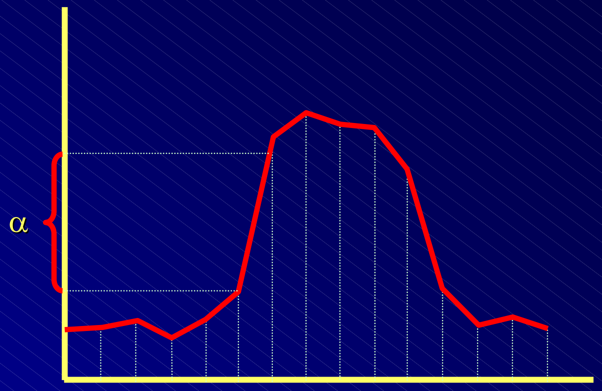
Timeout Period

- Two parameters: t_{max}, t_{avg}
- A critical packet is retransmitted t_{max} after its transmission if it is not acknowledged.
- If (numberOfEventsintheList>listSize-n)

```
If (numberOfEventsintheList>listSize-n)
        for(allEventsintheList)
                if(eventTime≥t_max || eventTime≥t_avg)
                        retransmit(event);
```

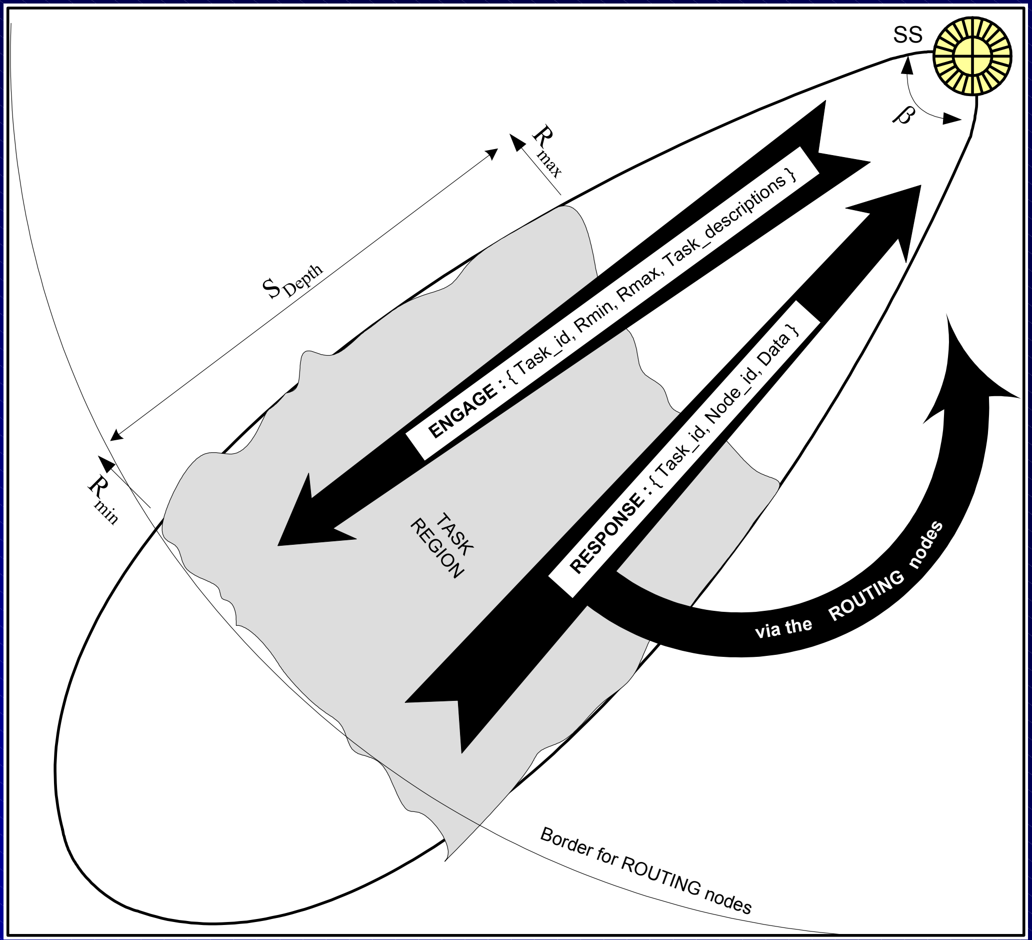
- $t_{avg} = \beta\, t_{avg} + (1 - \beta)\, t_{ack}$

Enforced Acknowledgement



- The source node marks the critical packet.
- The receiver acknowledges the marked packet.
- If the sender does not receive an acknowledgement for the critical packet during the timeout period, it retransmits the critical packet.

Blanket Acknowledgement



A. Erdogan, E. Cayirci, V. Coskun, "Sectoral Sweepers for Sensor Node Management and Location Estimation in AdHoc Sensor Networks," Proceedings of the MILCOM 2003.

Blanket Acknowledgement is used in SENDROM application.

E.Cayirci, T.Coplu, "Sensor Networks for Disaster Relief Operations Management," submitted to MedHocNet 2004.

Conclusion

- End-to-end reliable event transfer concept can reduce the control traffic for end-to-end reliability as well as it maintains the required level of end-to-end reliability.

- We can classify end-to-end event reliability schemes as follows:

1. Schemes not based on acknowledgements
    - a. Frequency based
    - b. Density based

2. Schemes based on acknowledgements
    - a. Selective acknowledgement
    - b. Enforced acknowledgement
    - c. Blanket acknowledgement

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Erdal Cayirci

Data Aggregation

Categorization of Data Aggregation Schemes:

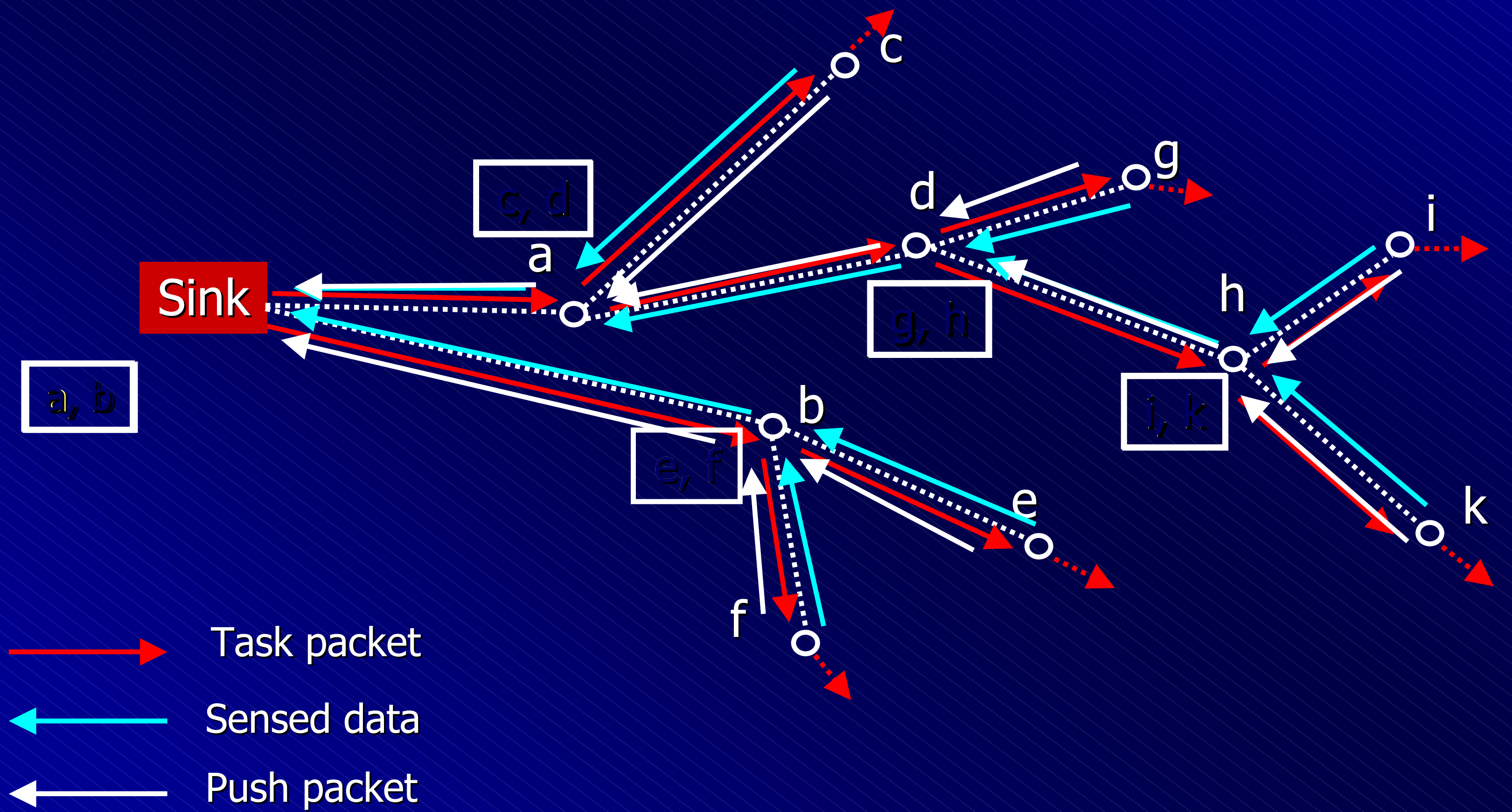
1. **Temporal or spatial aggregation,**

2. **Snapshot or periodical aggregation,**

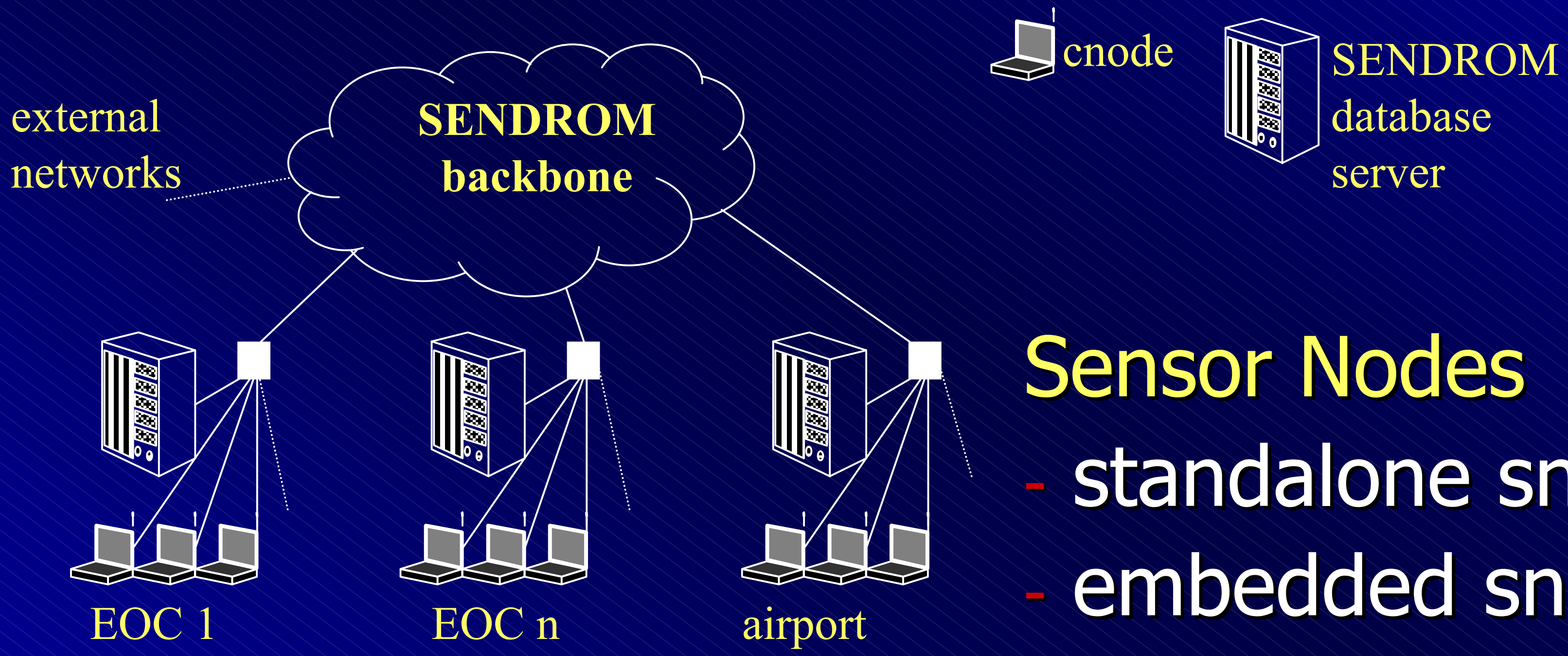
3. **Centralized or distributed aggregation,**

4. **Early or late aggregation.**

Data Aggregation and Dilution by Modulus Addressing



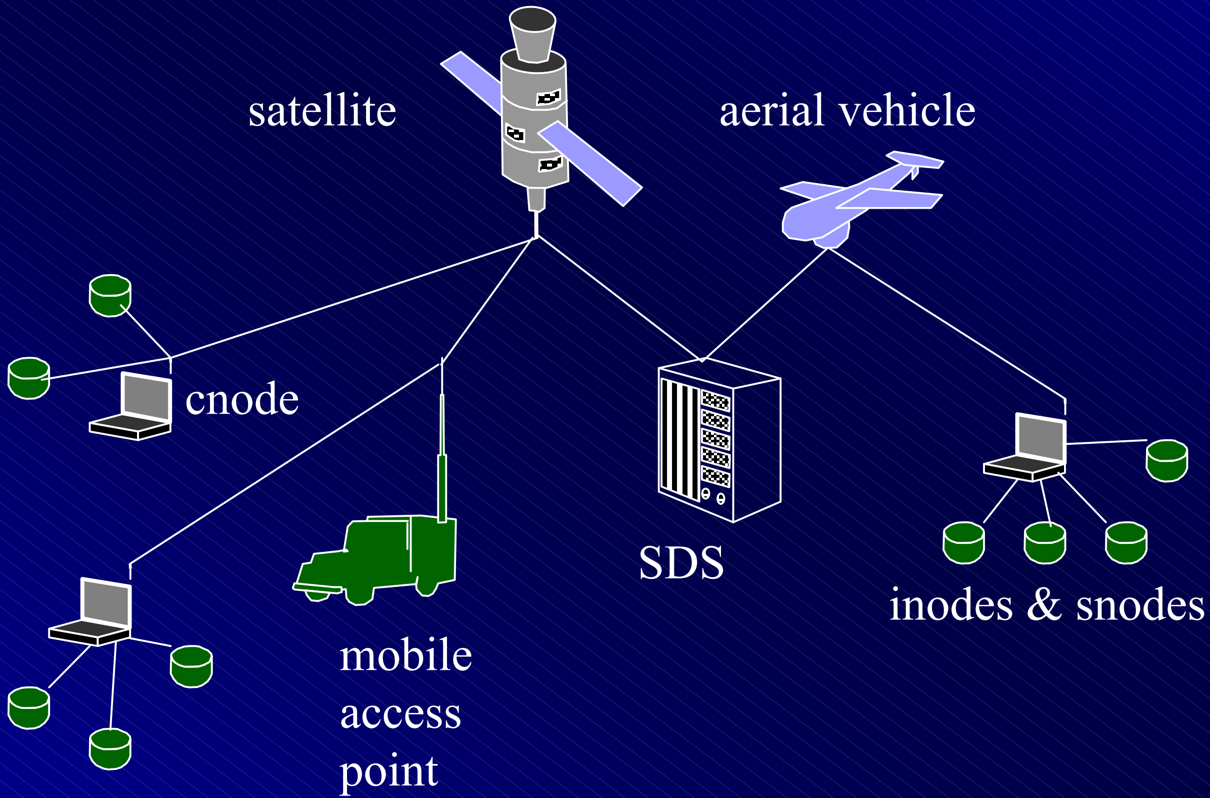
SENDROM: Sensor Networks for Disaster Relief Operations Management



Sensor Nodes

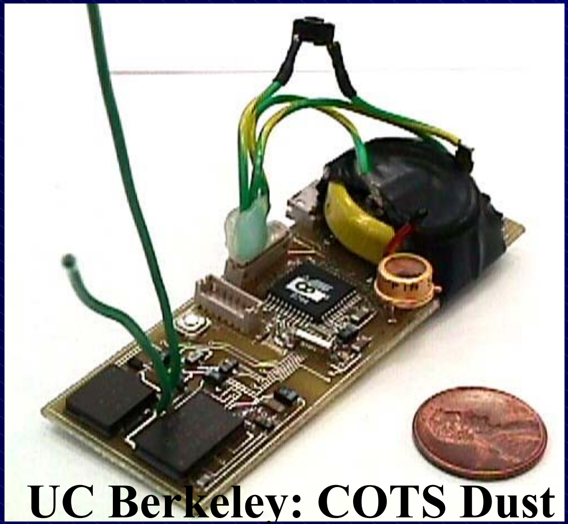
- standalone snodes,
- embedded snodes,
- standalone inodes,
- embedded inodes

SENDROM (Cont'd)



Sensor Nodes

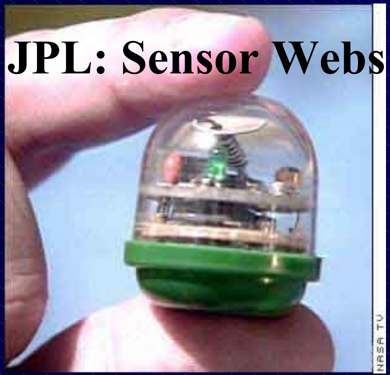

UC Berkeley: COTS Dust


UC Berkeley: COTS Dust

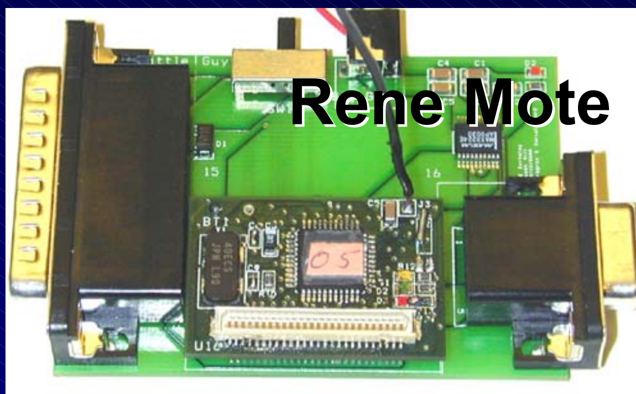
UC Berkeley: Smart Dust

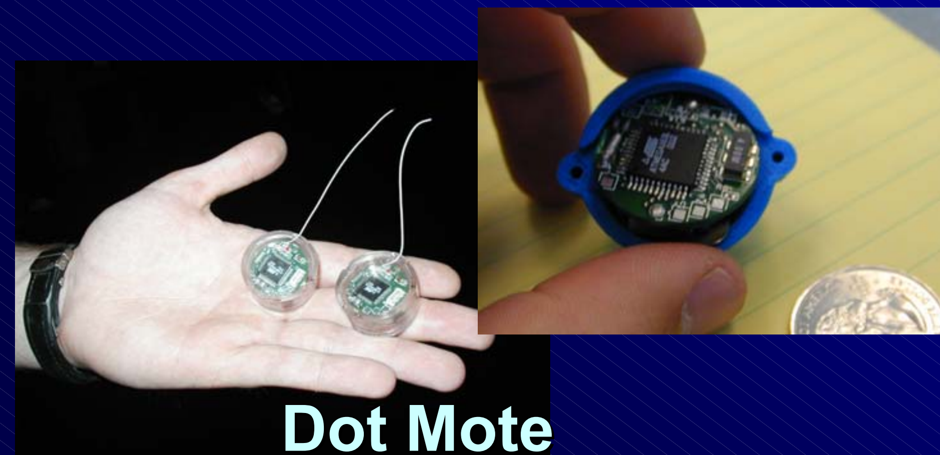

UCLA: WINS

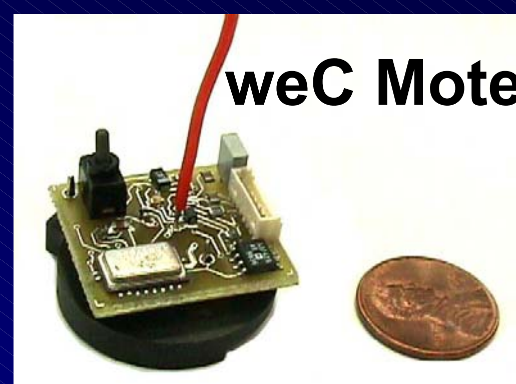

Rockwell: WINS

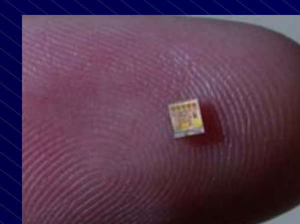

JPL: Sensor Webs

Sensor Nodes









Sensor Nodes

Duyarga D-256 (Experimental sensor node)

- RF 860-930
- 4 ADC (RJ45)
- 1 RS 232
- 256 K Flash, 20 K RAM
- MAC and higher layer protocols can be reimplemented

Sensor Nodes

	1980's-1990's	2000-2003	2010
Manufacturer	custom contractors	Crossbow, Sensoria, Ember, etc	Dust, Inc, and others
Size	large shoe box	small shoe box	dust particle
Weight	kilograms	grams	negligible
Architecture	separate sensing, proc., comm. units	integrated	integrated
Topology	point-to-point, star	client server, peer-to-peer	peer-to-peer
Power supply	large batteries hours, days, longer	AA batteries days-to-weeks	solar months-to-years
Deployment	vehicle placed or air drop single sensors	hand-emplaced	embedded, sprinkled left behind

C. Chong, S.P. Kumar, "Sensor Networks: Evolution, Opportunities, and Chalenges," Proceedings of IEEE, Vol. 91, No. 8, August 2003.

Data Querying in Sensor Networks

- E. Cayirci,
  "Data Aggregation and Dilution by Modulus Addressing in WSNs,"
  IEEE Communications Letters, August, 2003.
- N. Sadagopan, B. Krishnamachari, A. Helmy,
  "The Acquire Mechanism for Efficient Querying in Sensor Networks,"
  Elsevier Ad Hoc Networks, (to appear).
- C-C Shen, et.al.,
  "Sensor Information Networking Architecture and Applications",
  IEEE Personal Communications Magazine, pp. 52-59, August 2001.
- C. Cimen, E. Cayirci, V. Coskun,
  "Querying Sensor Fields By Using Quadtree Based Dynamic Clusters and Task Sets,"
  Proc. of the MILCOM 2003.

Data Querying in Sensor Networks

- A. Helmy,
  "Mobility-Assisted Resolution of Queries in Large-Scale Mobile Sensor Networks"
  Special Issue Computer Networks (Elsevier) on Wireless Sensor Networks.
- R. Govindan, et.al.,
  "The Sensor Network as a Database,"
  Technical Report 02-771, USC, September 2002.
- P. Bonnet, J.E. Gehrke, and P. Seshandri,
  "Querying the Physical World,"
  IEEE Personal Communications, Vol. 7, No. 5, October 2000.

Data Querying in Sensor Networks

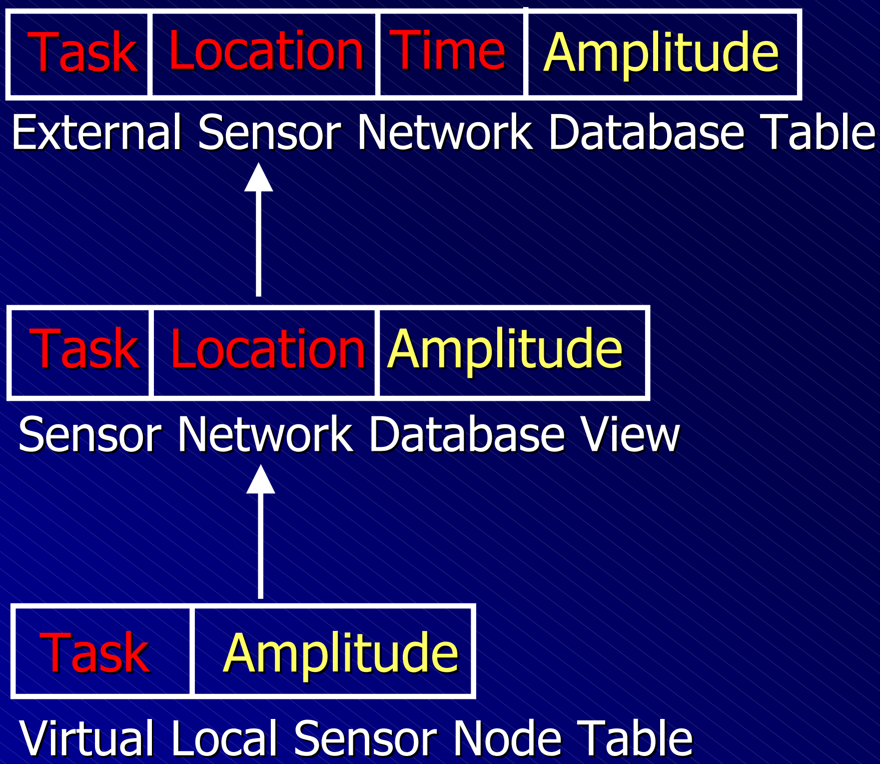
1. **Continuous queries,**

2. **Aggregate queries,**

3. **Complex queries,**

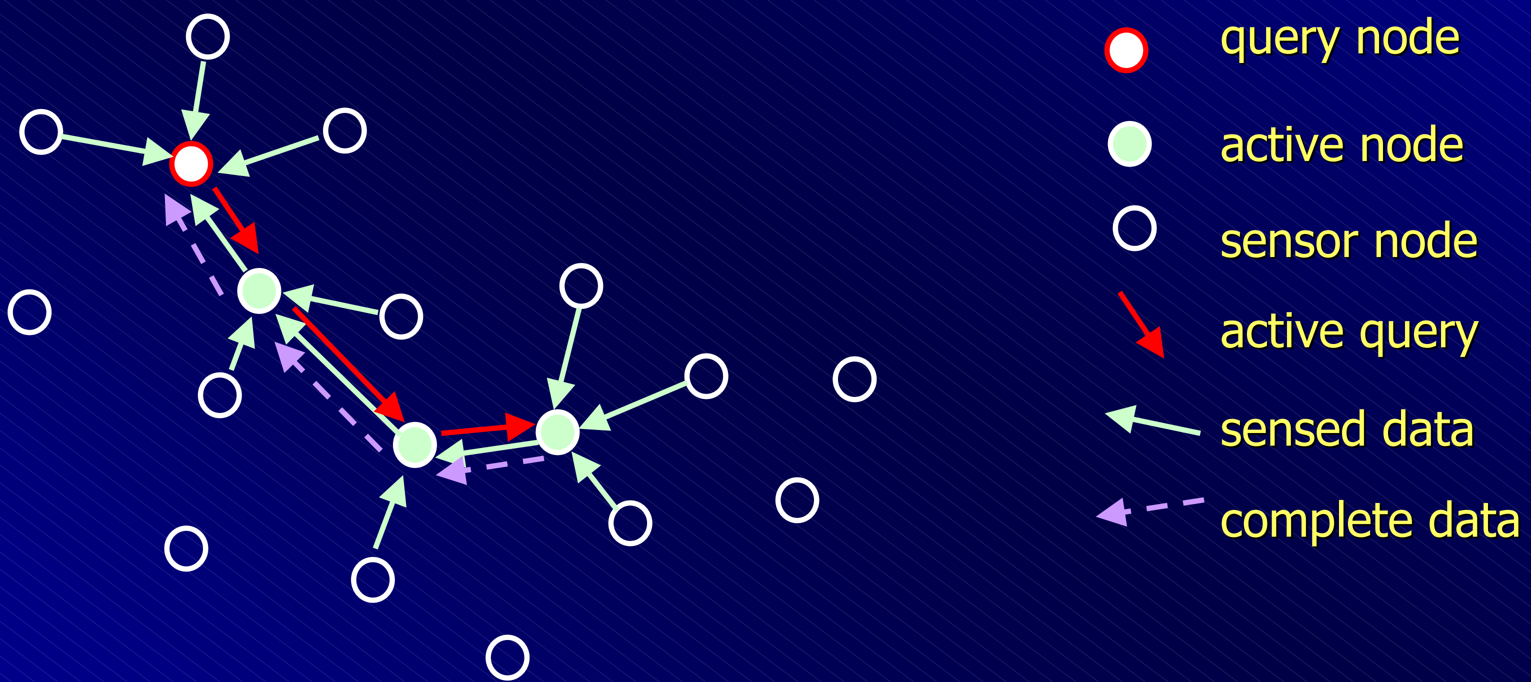
4. **Queries for replicated data.**

DADMA: Data Aggregation and Dilution by Modulus Addressing

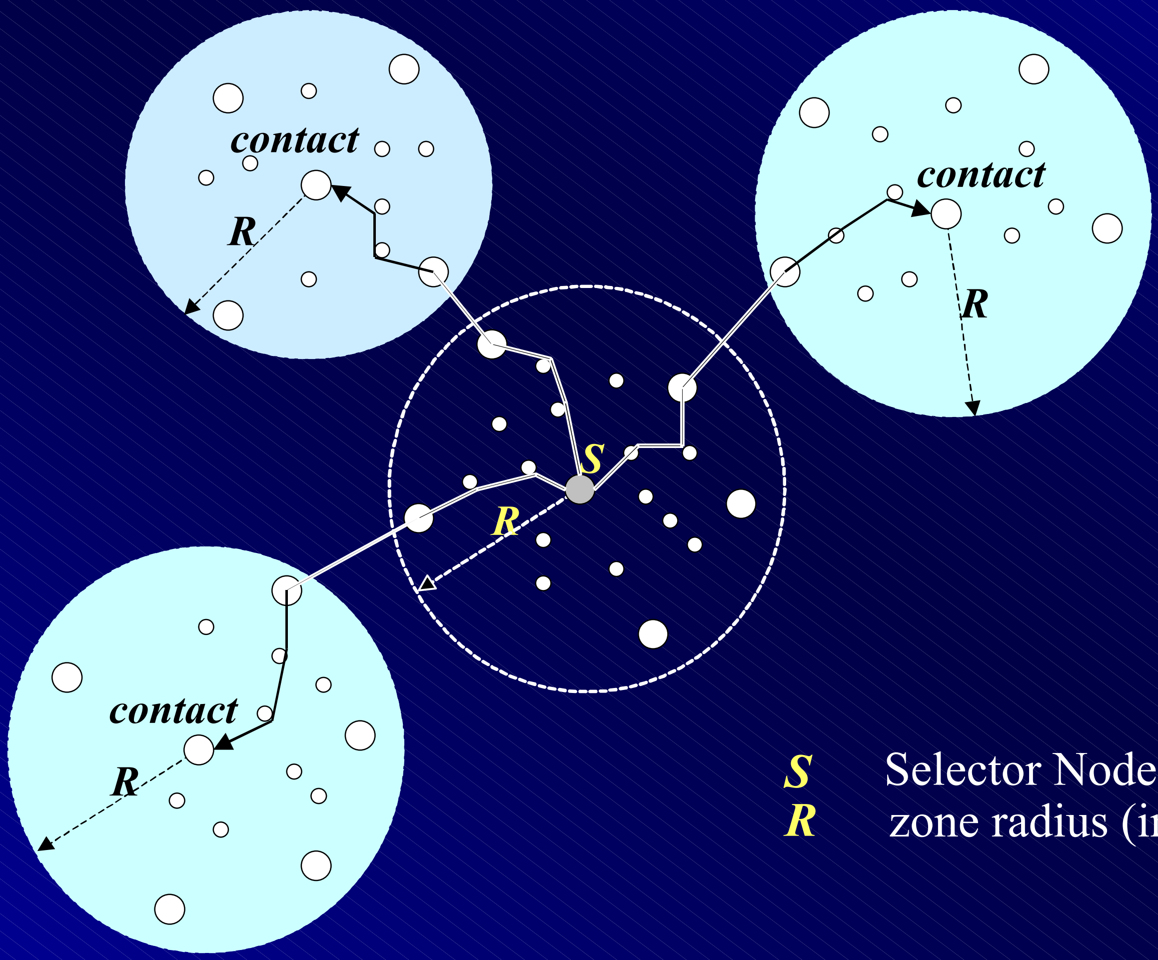


Select [task, time, location, [distinct | all], amplitude,
[[avg | min |max | count | sum] (amplitude)]]
from [any , every , aggregate *m* , dilute *m*]
where [power available [<|>] *PA* |
location [in | not in] *RECT* |
t_{min} < time < t_{max} |
task = *t* |
amplitude [<|==|>] *a*]
group by task
based on [time limit = l_t | packet limit = l_p |
resolution = *r* | region = *xy*]

ACQUIRE:


query node
active node
sensor node
active query
sensed data
complete data

Mobility-Assisted Resolution of Queries in Large-Scale Mobile Sensor Networks



S Selector Node
R zone radius (in hops)

Sectoral sweepers