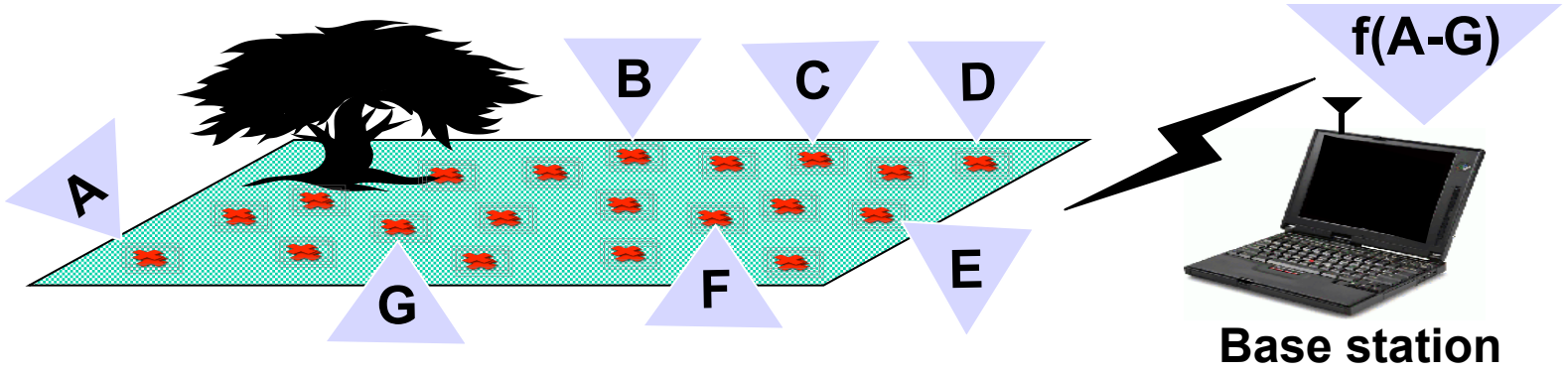
LEACH: An Application-Specific Protocol Architecture for Wireless Microsensor Networks

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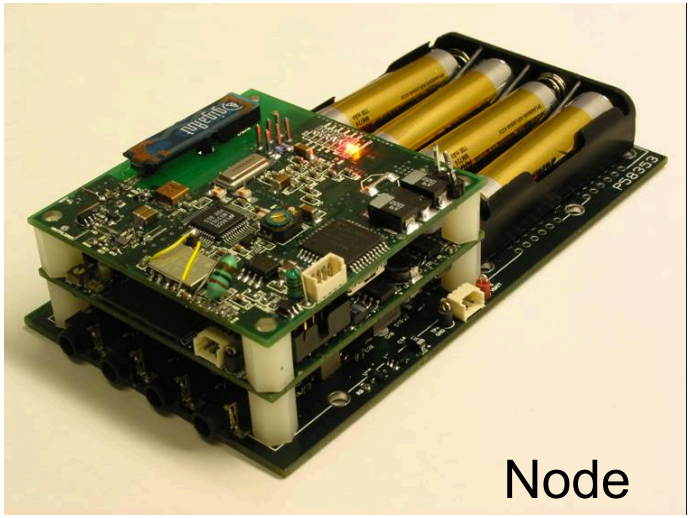
Sensor Networks

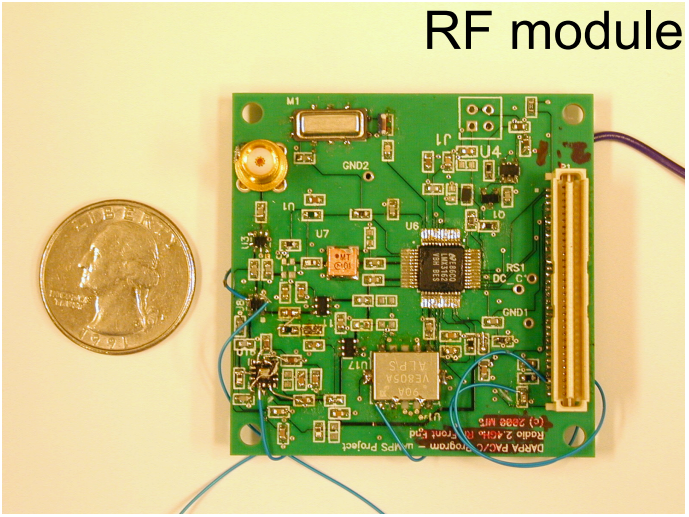


- **Remote monitoring of the environment**
  - **Surveillance**
  - **Machine diagnostics**
- **Relevant parameters:**
  - **System lifetime (energy efficiency)**
  - **Quality**
  - **Latency**

Context: MIT μ-AMPS Project (1999)

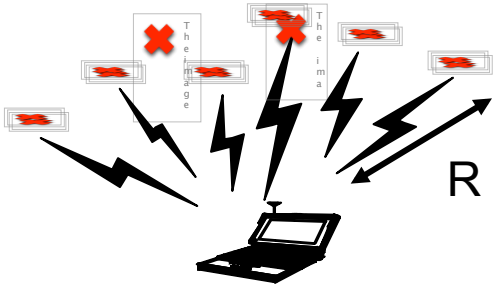
- **Energy-optimized sensors**
  - Node architecture and radio hardware
  - OS, algorithms, and protocols
- **Assumptions:**
  - Base station far from nodes
  - All nodes energy-constrained
  - Locally, data correlated
- **Communication protocols important**


Node

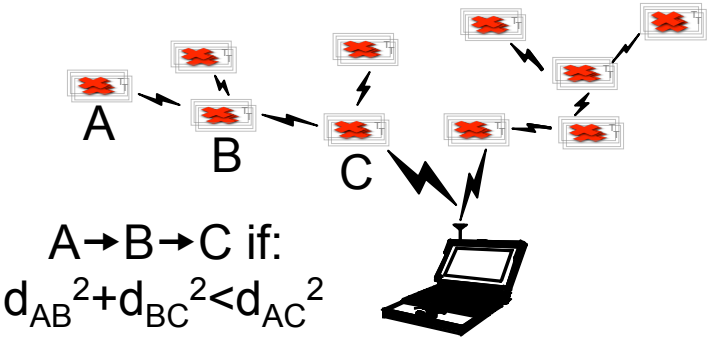

RF module

Prior Work

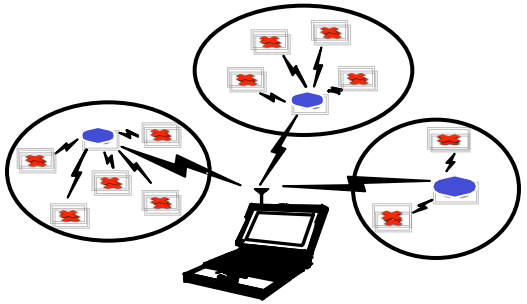
- **Direct transmission**
  - Energy scales as R^n



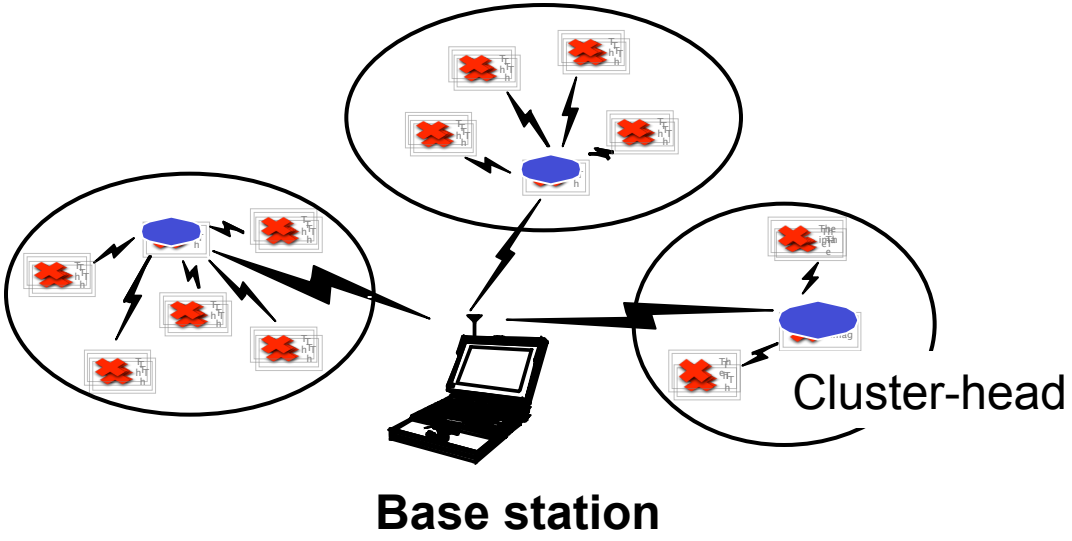
- **Routing**
  - E.g., Min transmission Energy
  - Multi-step communication
  - Short lifetimes for close nodes



- **Clustering**
  - Cellular model
  - Needs high-energy cluster-head

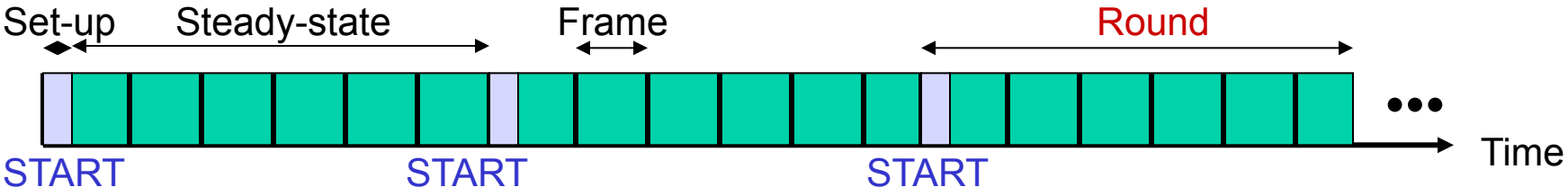


LEACH



- Low-Energy Adaptive Clustering Hierarchy
  - Adaptive, self-configuring cluster formation
  - Localized control for data transfers
  - Low-energy medium access
  - Application-specific data aggregation

LEACH Operation



- **Randomized cluster formation**
  - Each node decides to become cluster-head with some probability
  - Picked so the expected number of cluster-heads is *k*
  - *k* is a system parameter (and there's a way to pick a good *k*)
- **Rotate cluster-heads each round**
  - Clusters formed during set-up
  - Data transfers during steady-state
  - Requires nodes to be synchronized

Distributed Cluster Formation

$$\mathrm{E}[\#\,\mathrm{CH}] = \sum_{i=1}^{N} \mathrm{P}_i(t) * 1 = k$$

$$\mathrm{P}_i(t) = \begin{cases} \dfrac{k}{N - k * r \bmod (N/k)} & \mathrm{C}_i(t) = 0 \\ 0 & \mathrm{C}_i(t) = 1 \end{cases}$$

r +1 = current round of operation
k = system parameter
$C_i(t)$ = 1 if node i a CH in last r rounds

- Assumes nodes begin with equal energy
- Each node CH once in N/k rounds

Autonomous decisions lead to desirable emergent behavior

Unequal Initial Energies

$$P_i(t) = \frac{E_i(t)}{E_{total}(t)} k$$

$E_i(t)$ = energy of node i at time t
$E_{total}(t)$ = total energy in system at time t

High-energy nodes CH more often than low-energy nodes

If nodes begin with E_o

Cluster-head nodes

$E_i(t) \approx E_o - X$

Non-cluster-head nodes

$E_i(t) \approx E_o$

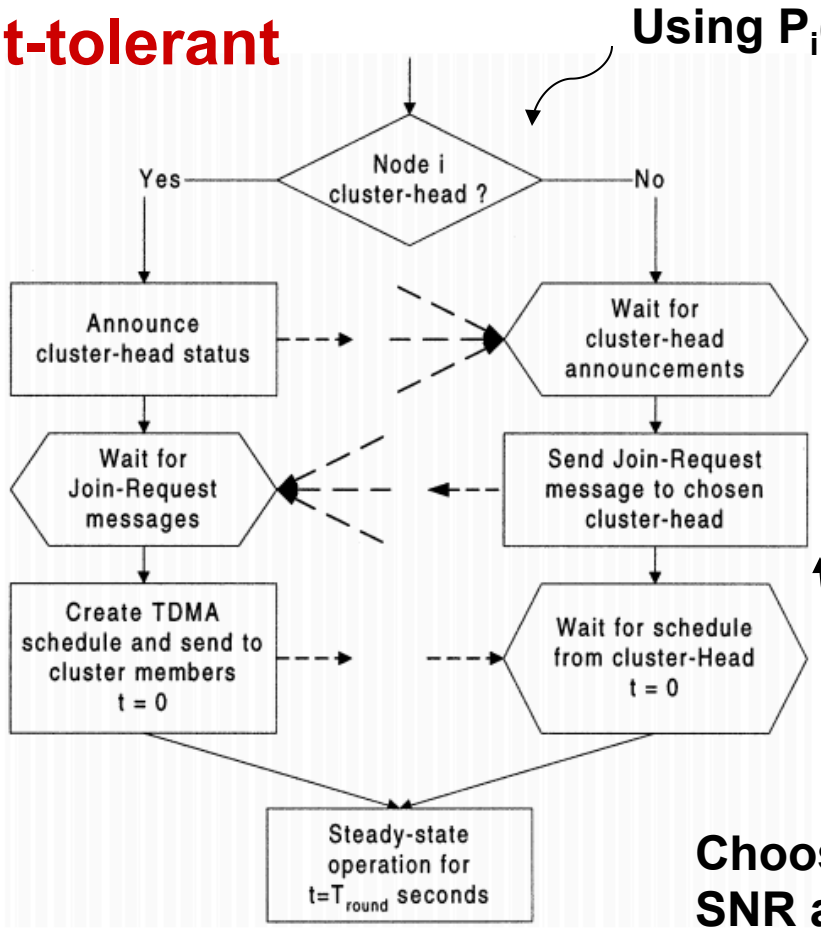
$$E_{total} \approx E_o(N-kr) + (E_o-X)kr$$

$P_i(t) \approx 0$

$P_i(t) \approx k/(N-kr)$

Distributed Cluster Formation Algorithm

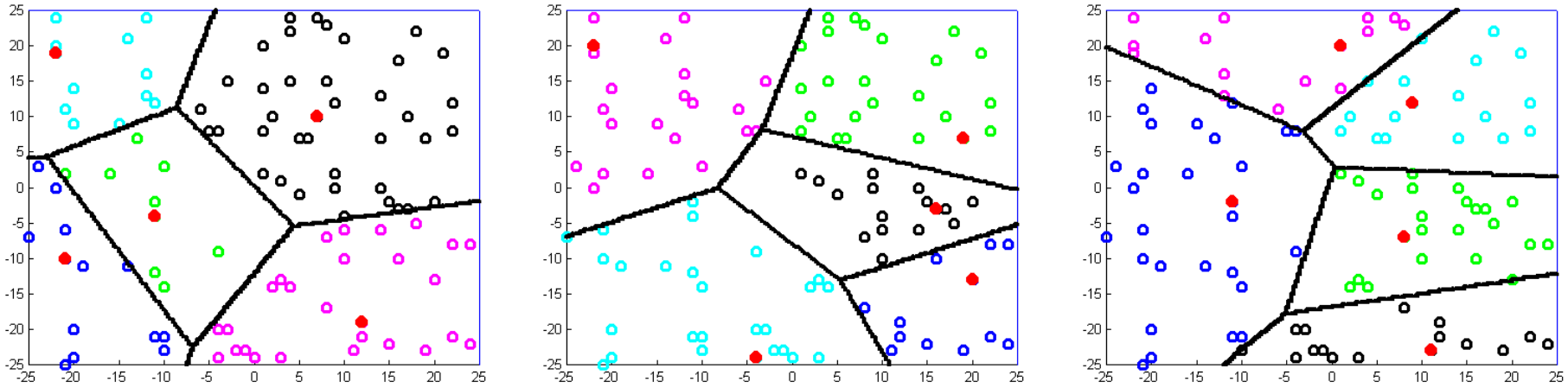
- No global control
- Flexible, fault-tolerant



Dynamic Clusters

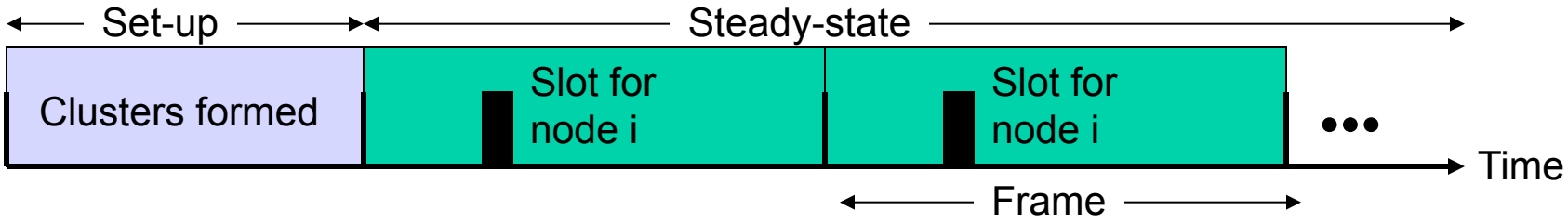
- **Adaptive clusters**
- **Rotation to evenly distribute energy load**

Clusters during different rounds in LEACH



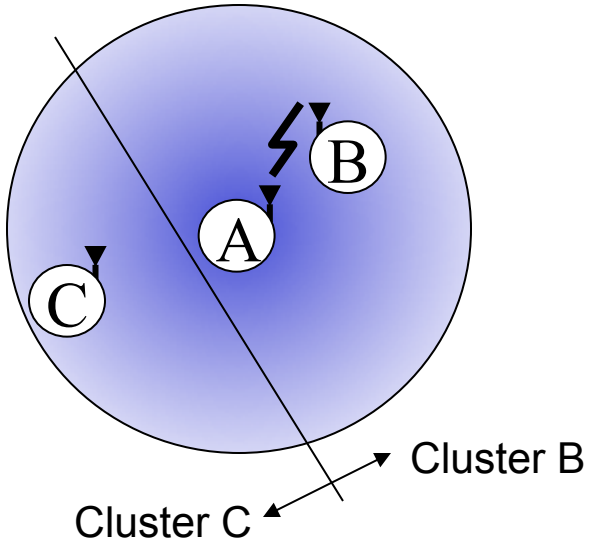
Cluster-heads = ●

LEACH Steady-State



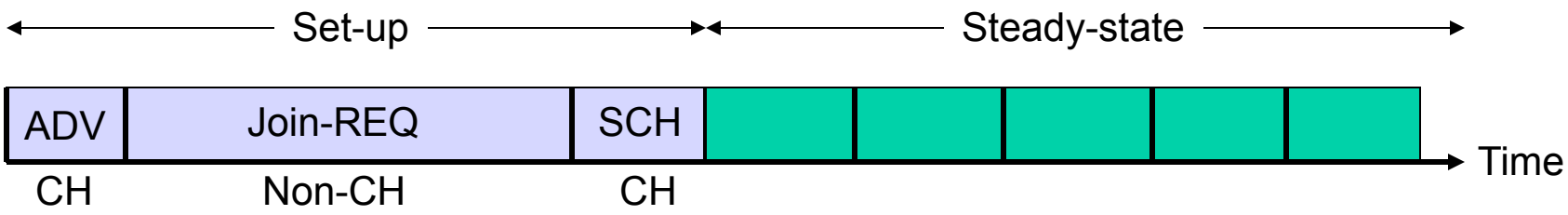
- **Cluster-head coordinates transmissions**
  - TDMA schedule
  - Node *i* transmits once per frame
- **Low-energy approach**
  - No collisions
  - Maximize sleep time

Inter-Cluster Interference



- **Transmission in different clusters can collide**
  - **Nodes minimize transmission power**
  - **Each cluster has unique, orthogonal spreading code (e.g., CDMA codes)**
  - **Distributed solution to minimize interference**

LEACH Medium Access



ADV

- **CSMA**
- **Large power, small messages**

Join-REQ

- **CSMA**
- **Large power, small messages**

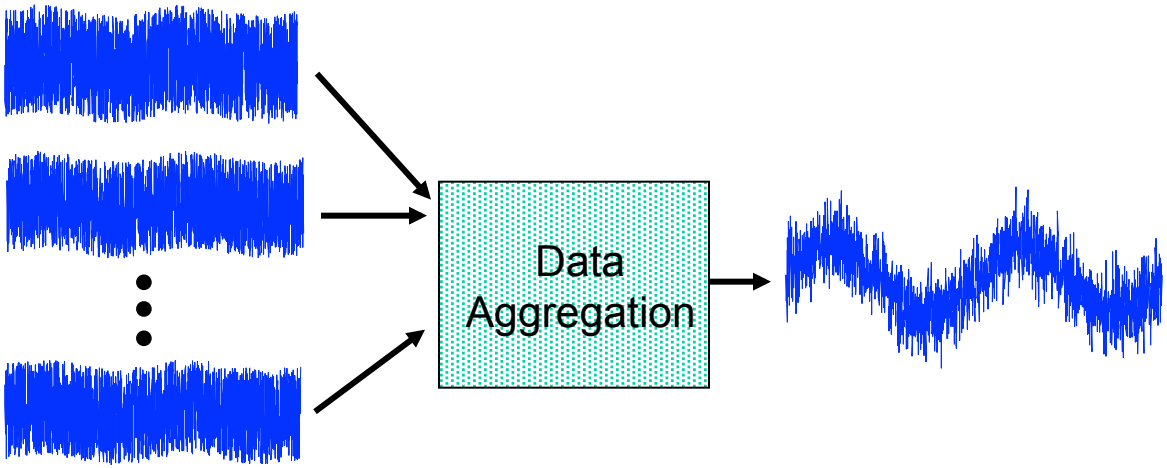
SCH

- **CDMA code**
- **Power to reach all members**

Data Transfer to CH

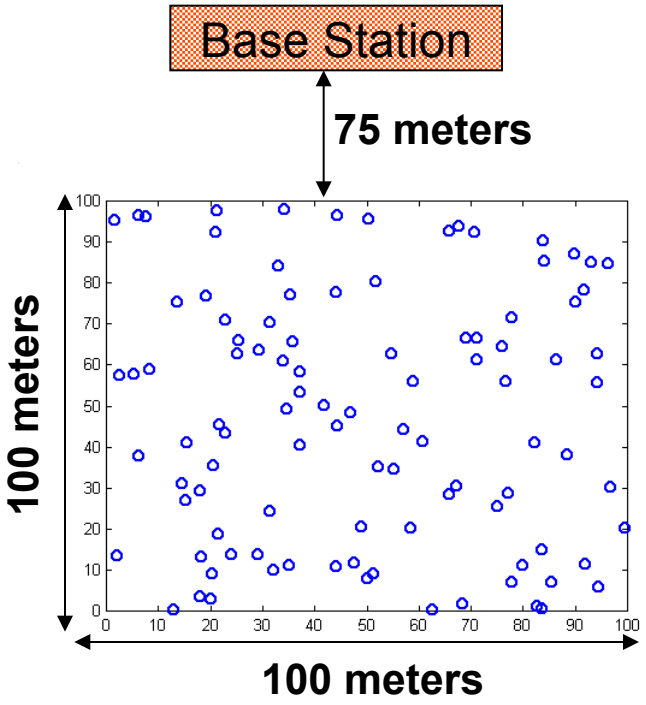
- **TDMA (with CDMA code) – no collisions**
- **Power to reach CH, large messages**

Application-Specific Data Aggregation



- Local sensor data often correlated
- Data aggregation
  - Common signal enhanced/noise reduced
  - Improved detection and classification
- Compute to reduce communication energy at cluster-head

Simulation Parameters



Nodes	100
Network size	100 m x 100 m
Base station location	(50,175)
Radio prop. speed	$3x10^8$ m/s
Processing delay	50 μs
Radio speed	100 kbps
Radio electronics	50 nJ/bit
Transmit amplifier	100 pJ/bit/m^2
Beamforming cost	5 nJ/bit/signal
Data size	500 bytes

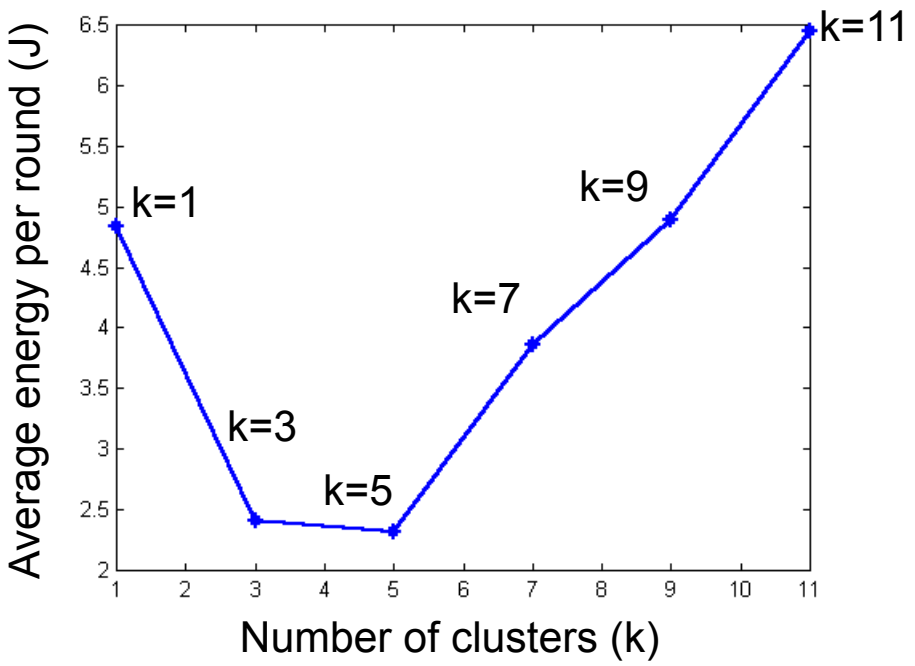
Optimum Number of Clusters, *k*

Analytic Result:

N=100
M=100
$75 < d_{toBS} < 185$

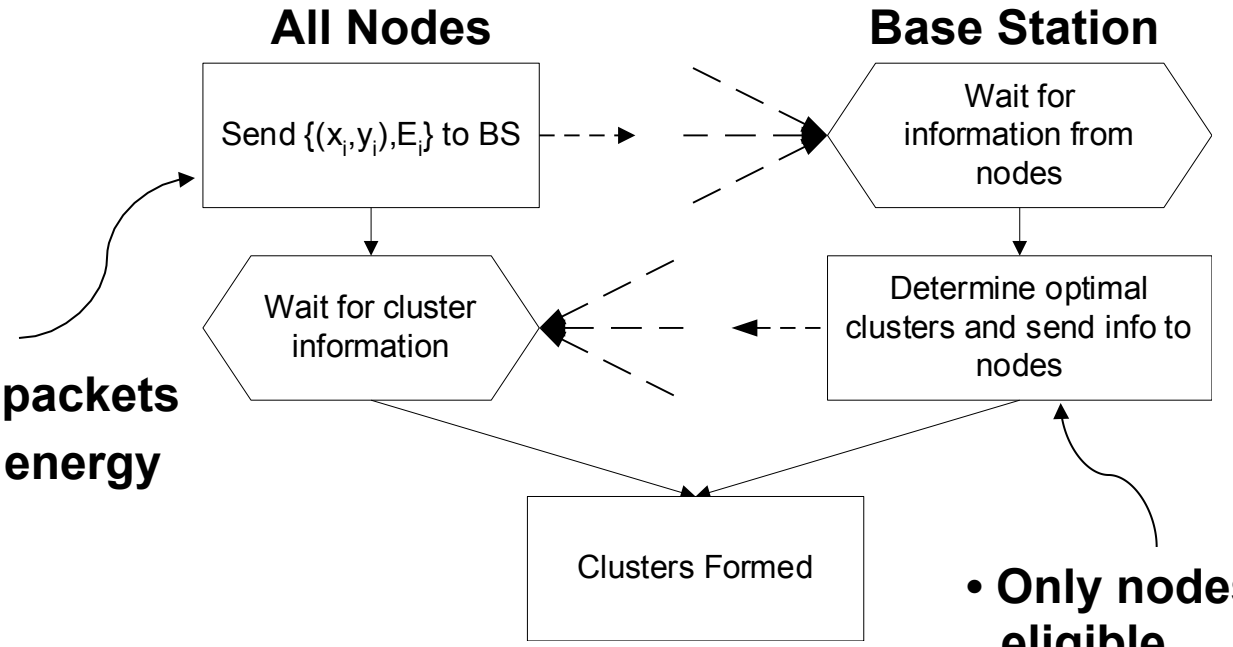
⇨ $2 < k < 6$

Simulation Result:



Centralized Cluster Formation (LEACH-C)

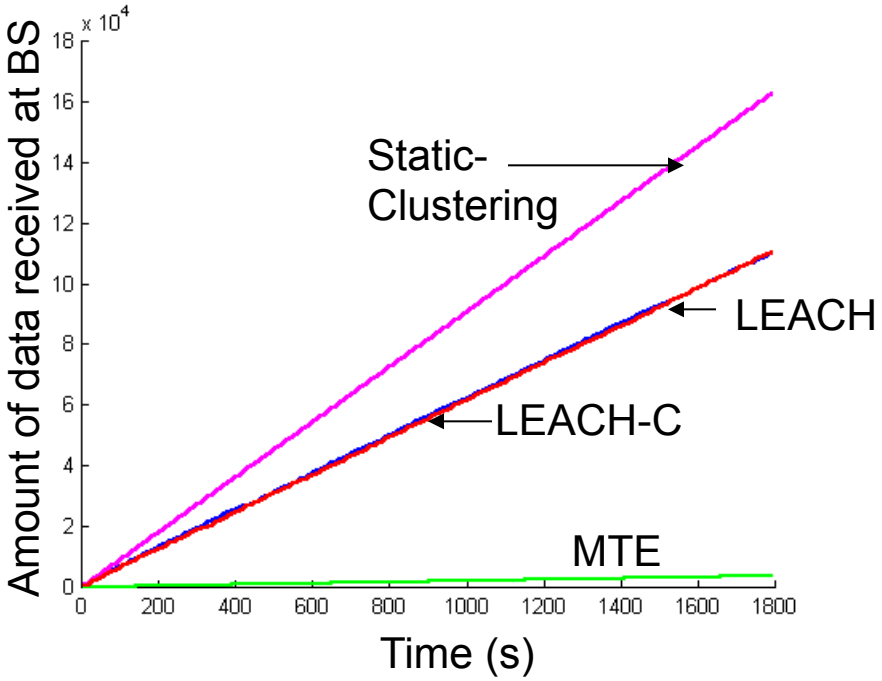
- Attempts to compute optimal clusters for comparison
- Needs GPS or other location-tracking method



- **Small packets**
- **Large energy**

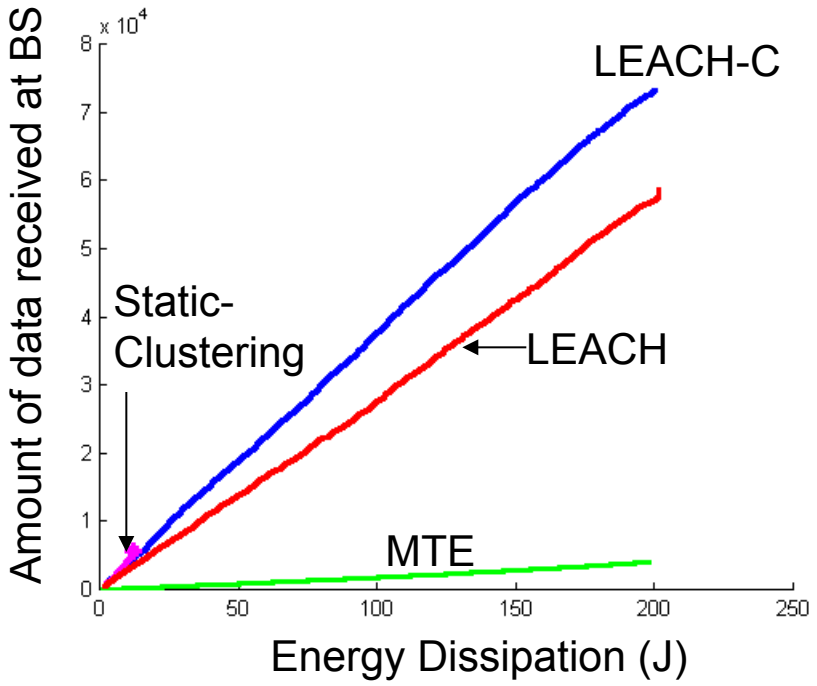
- **Only nodes with $E_i > \mu_E$ eligible**
- **Simulated annealing**

Simulations: Data Over Time (Assuming no energy constraints)



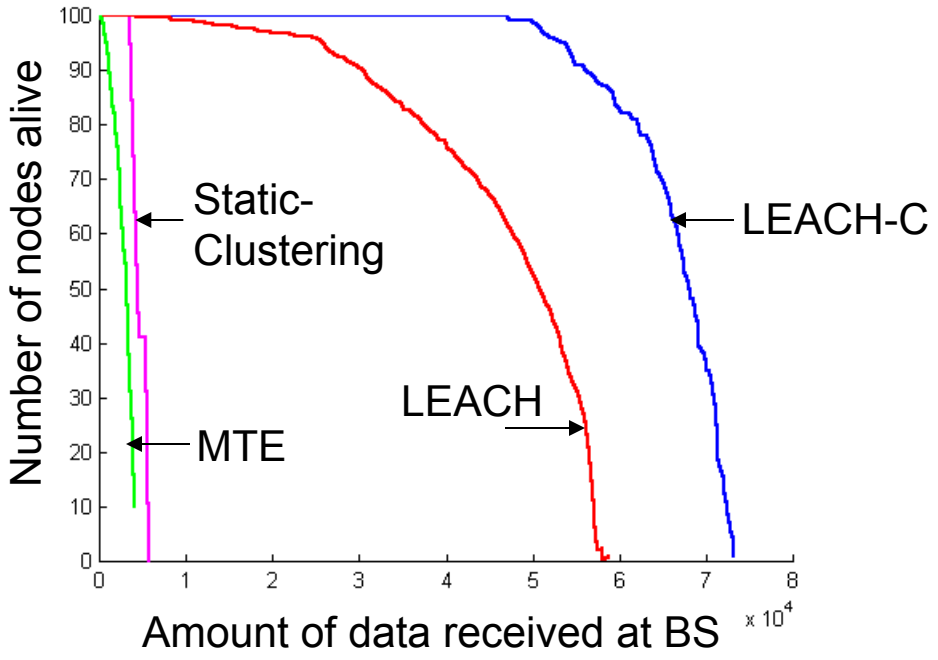
- **Static clustering: no set-up time**
- **LEACH data – 2 hops**
- **MTE data – 10 hops on average**

Simulations: Data per Energy



- LEACH achieves order of magnitude more messages per Joule
- Data aggregation successful

Network Lifetime with Limited Energy



- **LEACH delivers over 10 times amount of data over system lifetime**
- **Rotating cluster-heads is effective**