DESIGN AND DEVELOPMENT OF AN

ULTRA LOW POWER COMMUNICATION PROTOCOL

FOR WIRELESS AUTONOMOUS MICROSYSTEMS

Rob van Heijster

TNO | Knowledge for business

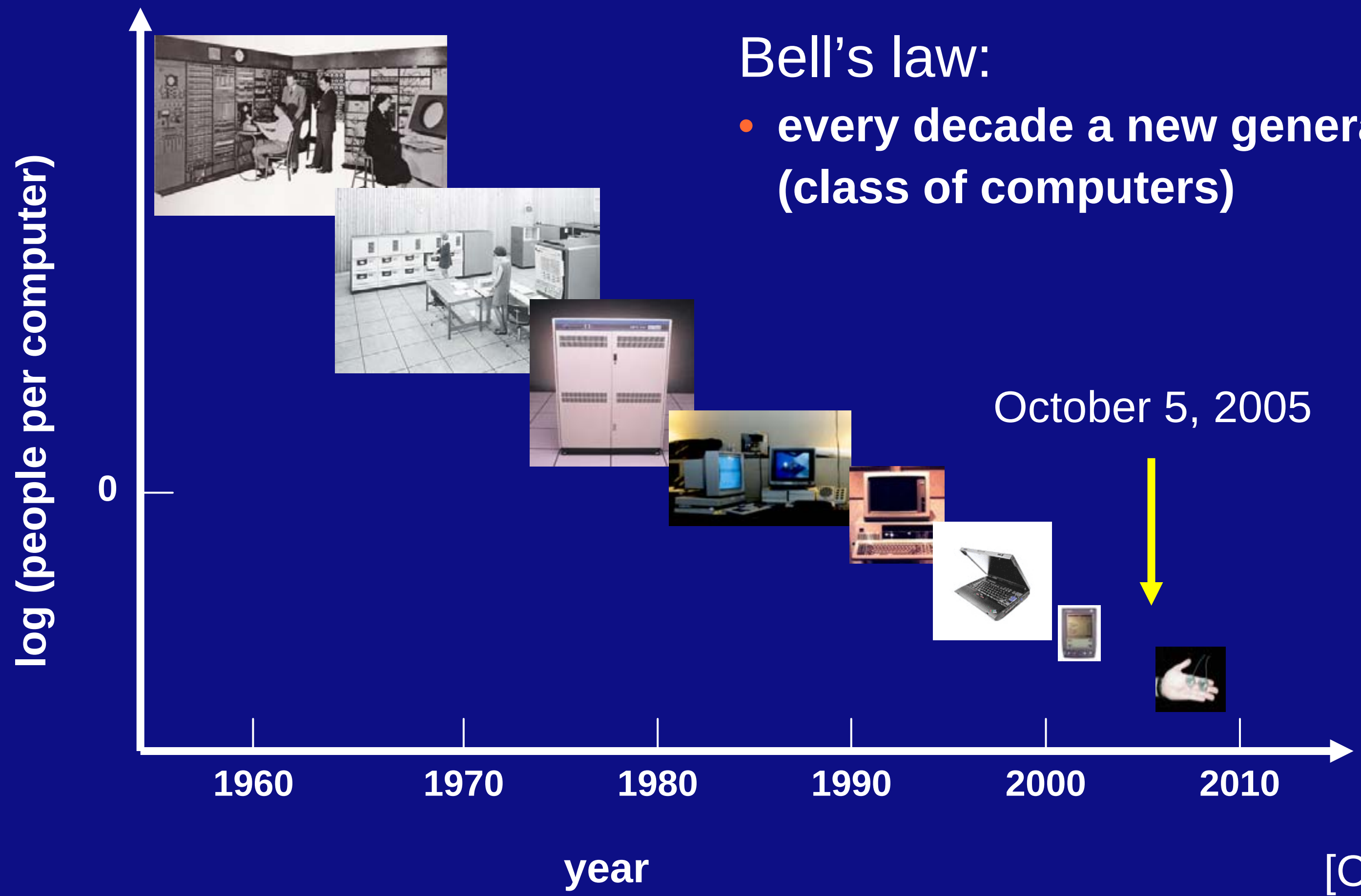
Outline

- Introduction
- Applications
- Communication nodes
- Protocols
- Conclusions

The next generation

Bell's law:

- **every decade a new generation (class of computers)**

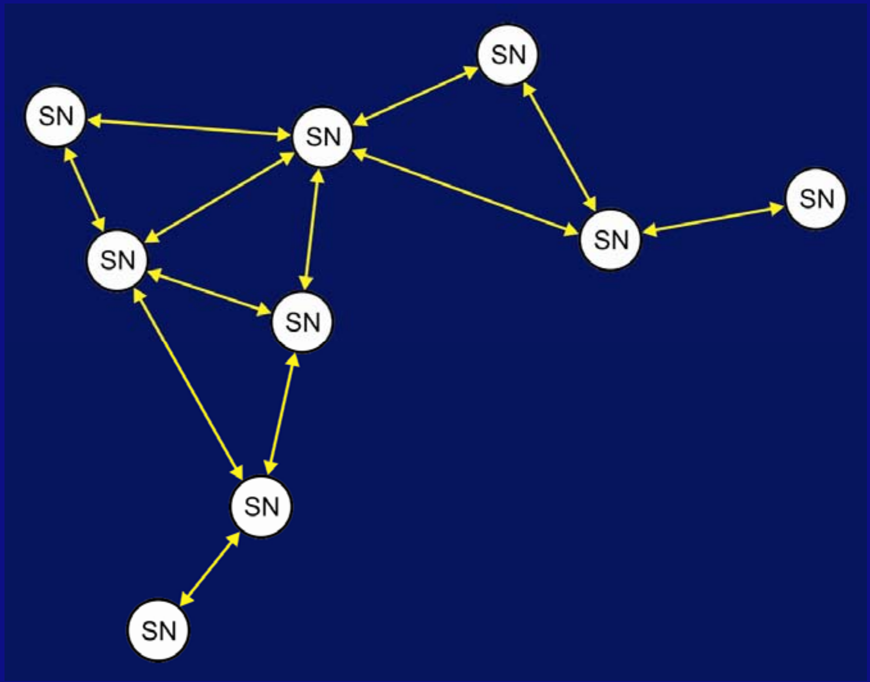


[Culler:2004]

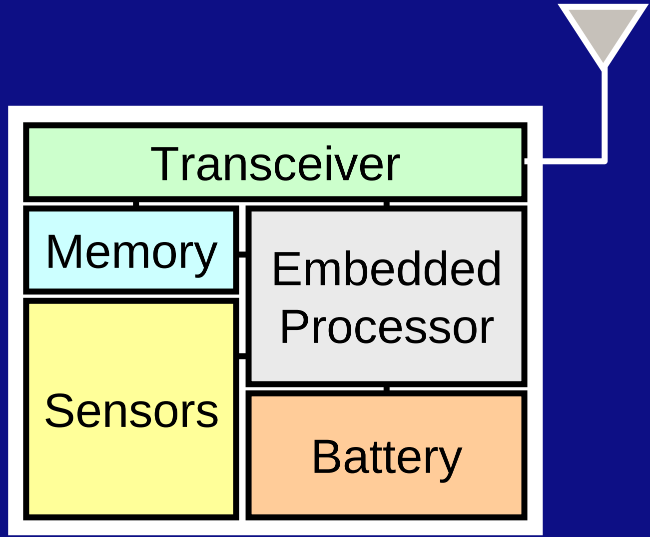
Introduction

Ultra low power protocol

- To connect autonomous micro-sensor systems
- Limited energy available
- **Sensor Nodes (SN's) autonomously ACT:**
  - Analyse environment
  - Communicate
  - Take action



Wireless Sensor Networks



Integrated devices

- **power supply**
- **sensors**
- **embedded processor**
- **wireless link**

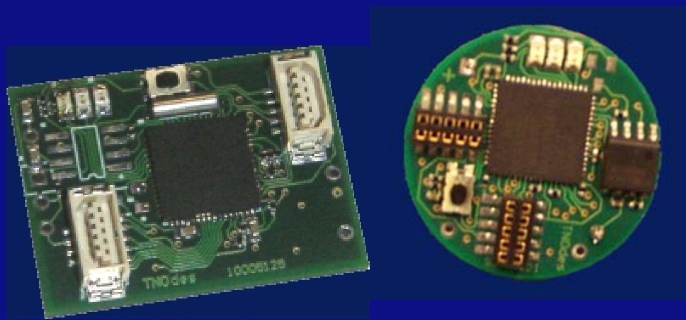
Many, cheap sensors

- **wireless → easy to install & operate**
- **intelligent → collaboration**
- **low-power → long lifetime**

Small size

- **Increased applicability**
- **Low production cost**
- **MST**
- **MCM (ASIC expensive)**

Autonomous sensor



TNOdes

The battery crisis
(Moore's law evil twin brother)

Limited capacity

<<<

~2 kcal (per battery) ~280 kcal (without cheese !)

Slow increase of capacity

- ~8% yearly increase (Wh/cm^3)
- doubles every 9 years

Decrease in energy consumption is decrease in size!

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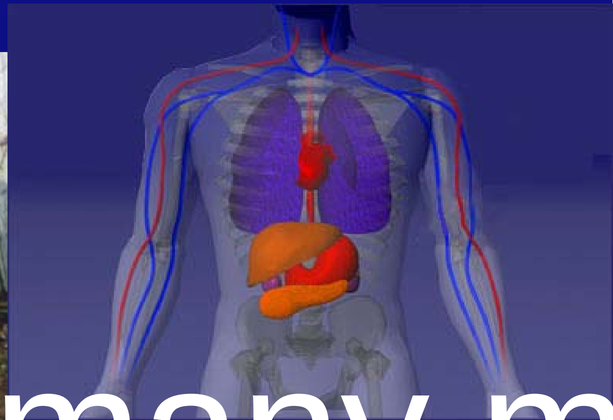
Sensor applications

Fire fighting

Medical



Process industry

and many more…

Urban warfare

Photo: ESA/NASA

Space

Photo: RNLN

Harbor defense

(Sensor) Applications

- Ad-hoc communication (no infrastructure)
  - Between swarms of (micro)-robots
  - Between (micro)-robots and spacecraft
- Intra-spacecraft (robust communication)

Photo: ESA

Photo: NASA

Applications @ TNO

Public safety

Homecare

Munitions' health monitoring

Photo: RNLA

Agriculture

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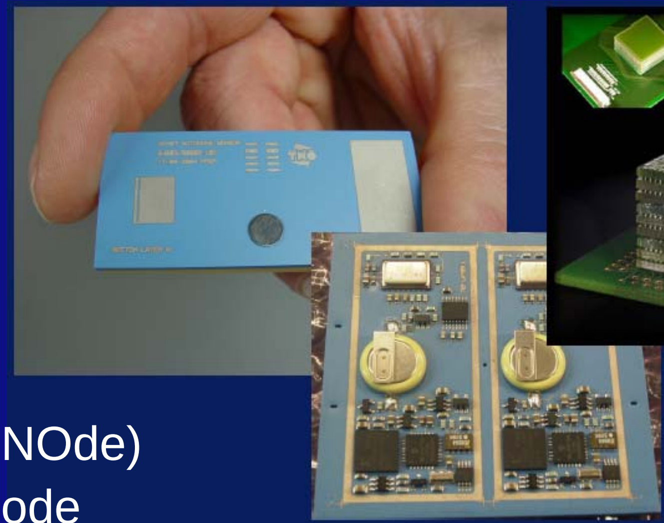
Autonomous sensor nodes

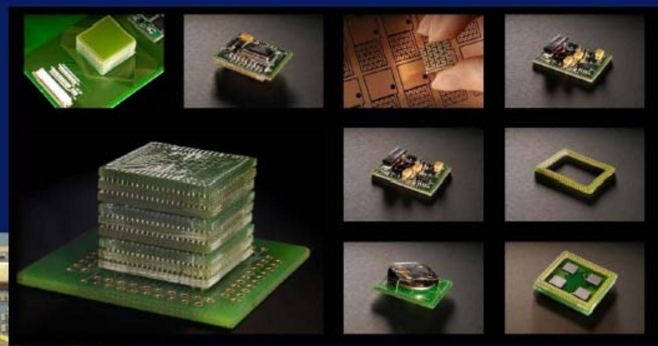
- Pressure sensor with 868 MHz tranceiver and 2,4 Ghz power harvesting

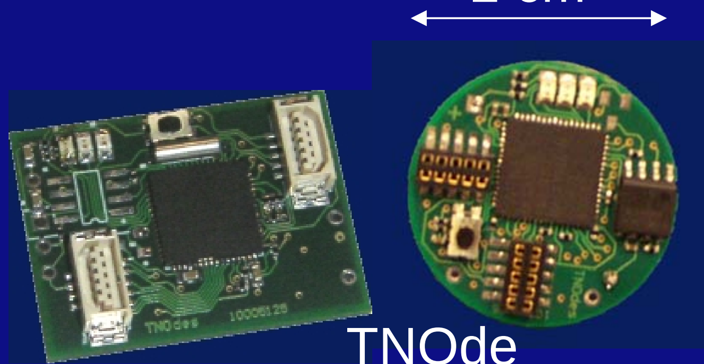


TNO node (TNOde)

- Universal node
- Universal sensor interface available
  - Analog
  - Digital
- T-MAC protocol

- Wireless microbrick sensors

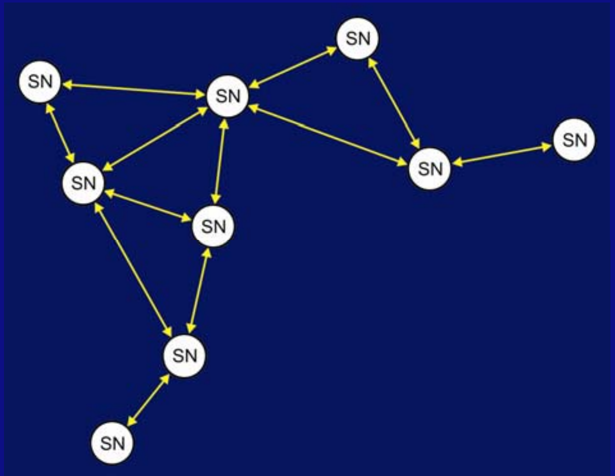




Research topics

Issues:

- node localization
- MAC protocols
- ad-hoc routing
- network intelligence
- energy harvesting
- …



Objectives / constraints:

- unattended operation
  - self-configuration
  - robustness
- limited resources
  - energy
  - memory

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Wireless MAC protocols

Control access to the shared medium (radio channel)

- **avoid interference between transmissions**
- **mitigate effects of collisions (retransmit)**

Approaches

- **contention-based: no coordination → CSMA/CA**
- **schedule-based: central authority (access point) → TDMA**

Traditional MAC protocols designed to:

- **maximize packet throughput**
- **minimize latency**
- **provide fairness**

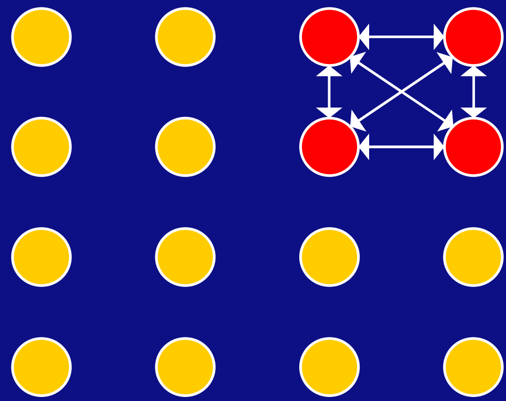
Communication patterns

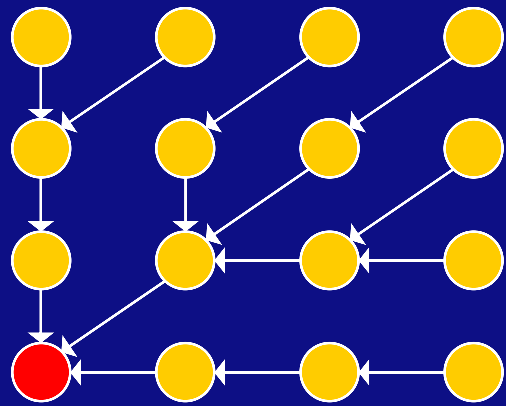
WSN applications:

- local collaboration when detecting a physical phenomenon
- periodic reporting to sink

Characteristics:

- low data rates < 1000 bps
- small messages ~ 25 bytes
- fluctuations (in time and space)


local gossip


convergecast

[Kulkarni:2004]

Requirements for the protocol

Handle scarce resources

- CPU: 1 – 10 MHz
- memory: 2 – 4 KB RAM
- radio: ~100 Kbps
- energy: small batteries

Unattended operation

- Plug & play
- Robustness
- Ad-hoc routing
- Long lifetime

Standards do not suffice!

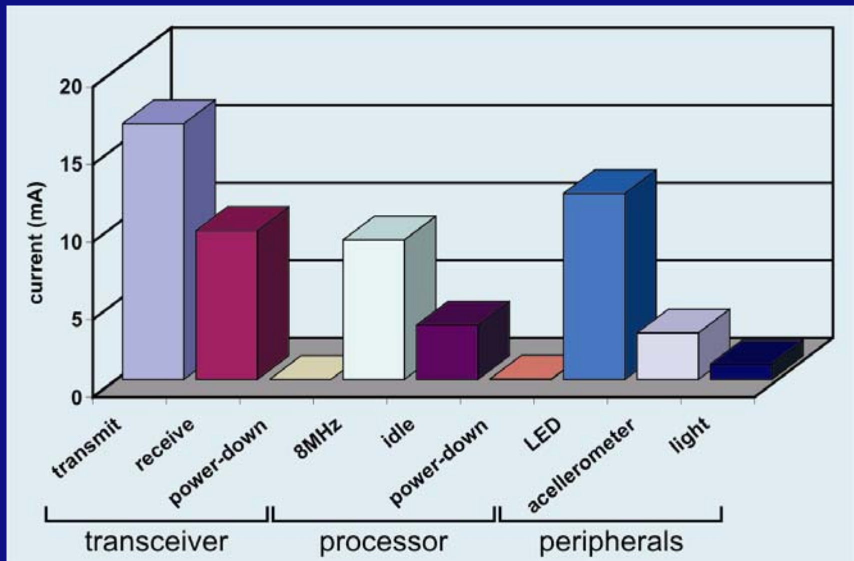
- 802.11
  - ad-hoc / hopping ✓
  - power consumption (power save mode not for multi-hop networks) ✗
  - memory footprint ✗
- Bluetooth
  - ad-hoc / hopping (limited network size) ✗
  - power consumption ✗
  - memory footprint ✗
- Zigbee
  - ad-hoc / hopping (no communication between RFDs) ✗✓
  - power consumption (continuous listening for peer-2-peer data transfers) ✗
  - memory footprint ✓

Design guidelines

- Switch radio off whenever possible (duty cycle) AND, minimize number of switches
- Low complexity (memory footprint)
- Minimize idle listening
- Trade off performance for energy
- Minimize overhead
- Optimize for traffic patterns

Goal:

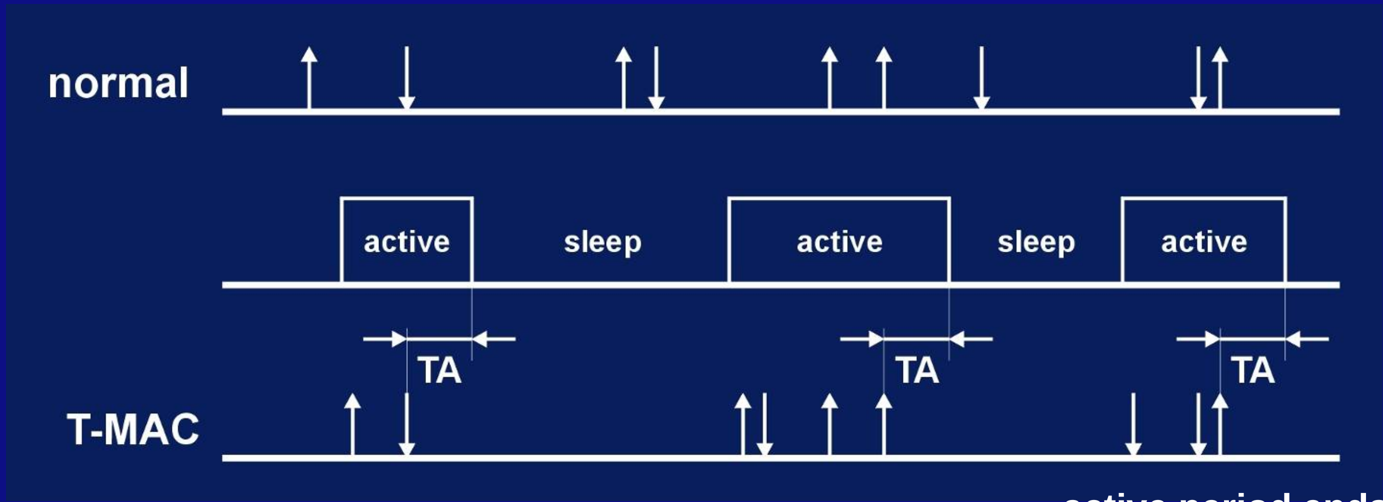
- Energy for communication
  <<
  Energy for sensing



Sources of overhead

- **idle listening** (to handle potentially incoming messages)
- **collisions** (wasted resources at sender and receivers)
- **overhearing** (communication between neighbors)
- **protocol overhead** (headers and signaling)
- **traffic fluctuations** (overprovisioning and/or collapse)
- **scalability/mobility** (additional provisions)

Dynamic duty-cycling: T-MAC



active period ends when no *activation event* occurs in TA

MAC protocol designed to:

- minimize energy consumption
  - prevent collisions
  - minimize protocol overhead
  - avoid overhearing
- support self-configuration

Conclusions

- Standard wireless protocols do not suffice for WSN, because of:
  - complexity (memory footprint)
  - power consumption (lifetime)
- Zigbee comes closest to being useful
  - only for particular deployment scenarios it suffices
- Solutions already exist @ TNO
  - extend Zigbee with T-MAC to truly support ad-hoc networking!

Thank you for your attention!

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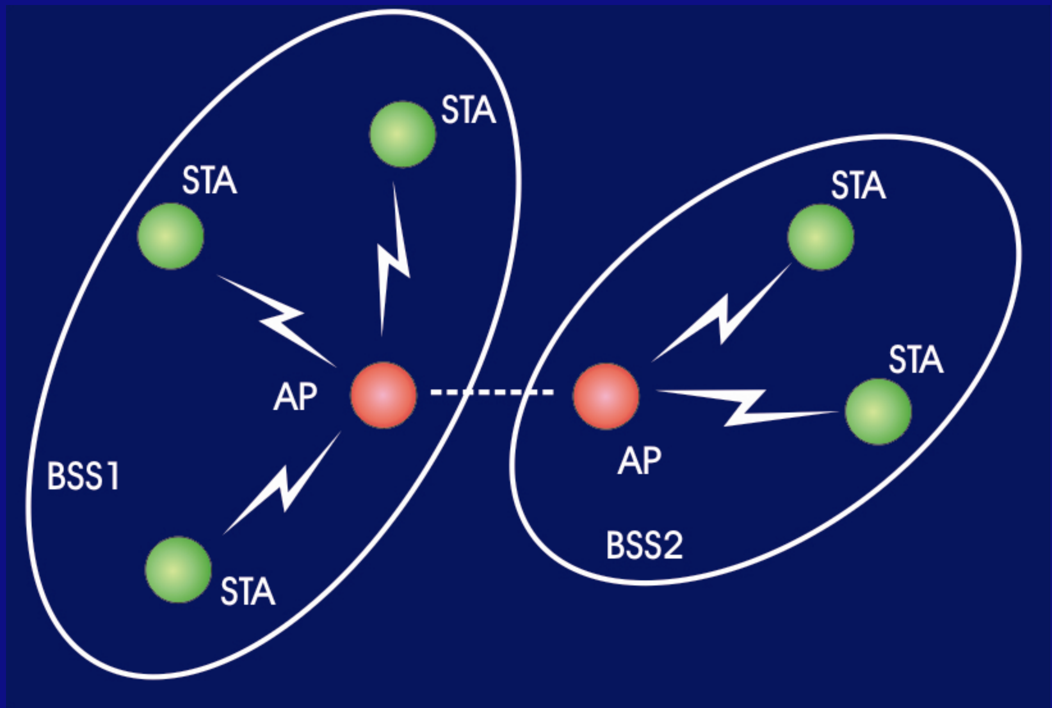
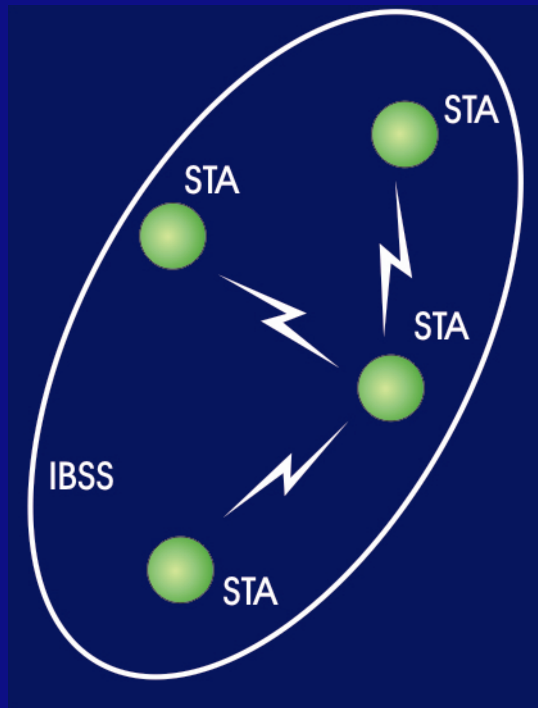
END

Spare slides

Standard 1: *802.11*



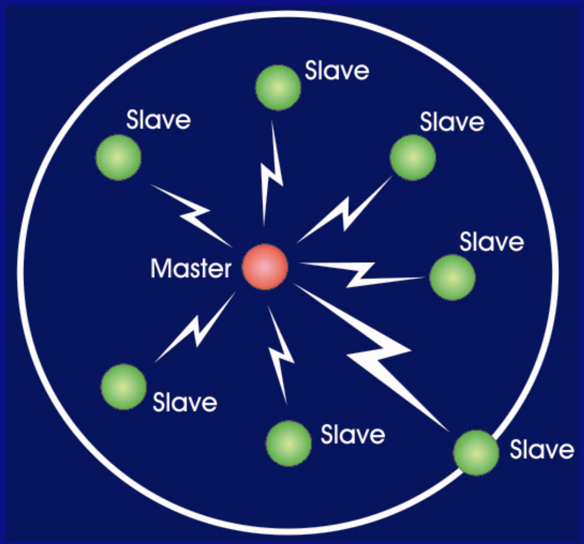
infrastructure mode



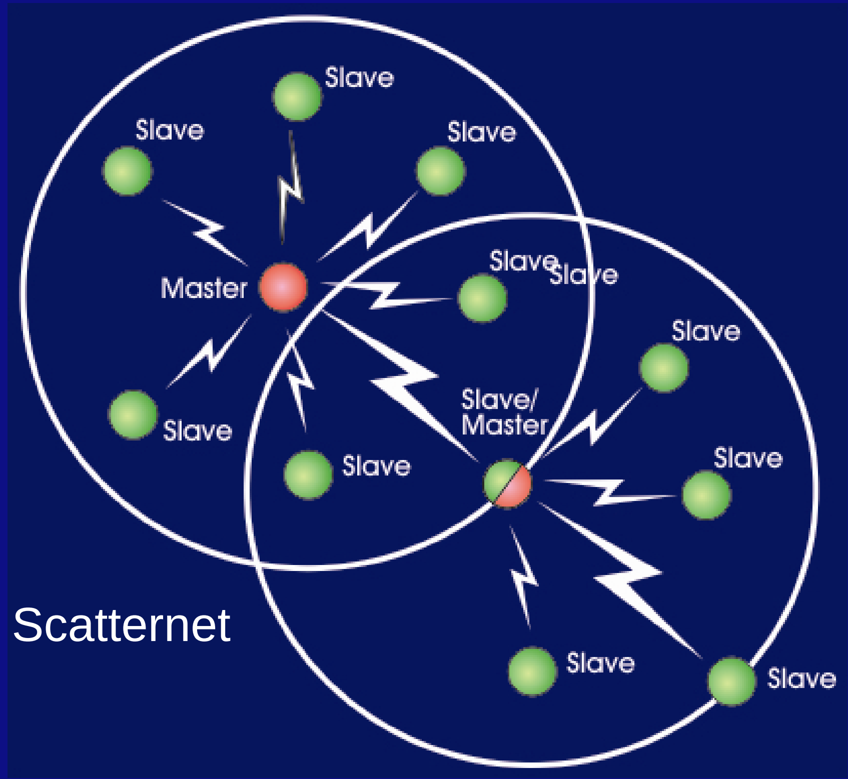
ad-hoc mode

- CSMA (optional CA)

Standard 2: *Bluetooth*



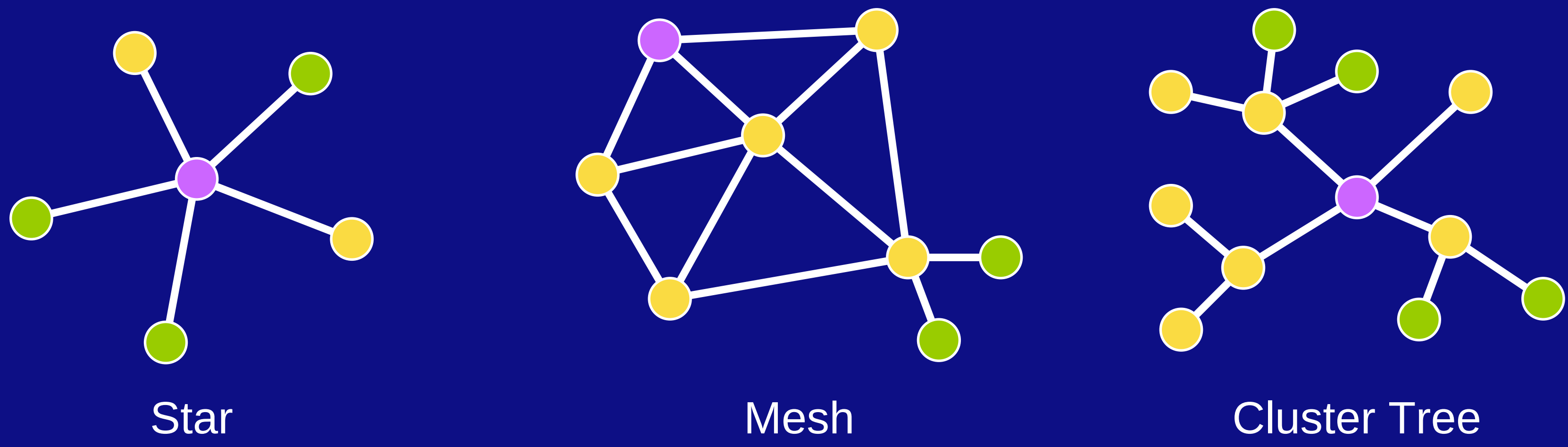
Piconet



Scatternet

- TDMA
- asynchronous / synchronous / isochronous data transports

Standard 3: *Zigbee ≈ 802.15.4*



- coordinated / uncoordinated communication
- slotted / unslotted CSMA/CA

PAN coordinator
Full Function Device
Reduced Function Device

[Zigbee Alliance:2004]

Standards overview

	Zigbee/802.15.4	Bluetooth/802.15.1	WLAN/802.11b
Application area	Monitoring	Cable replacement	E-mail, video, web
System requirements	4 - 32 kbyte	> 250 kbyte	> 1 Mbyte
Battery life (days)	100 - 1000	1 - 7	0.1 - 5
Network nodes	255 - 65k	7	30
Bandwidth (kbit/s)	250	720	>11.000
Range (m)	1-75	1-10	1 – 100
Key attributs	Cost, Power consumption	Cost, ease of usage	Fast and flexible
Source	*HELICOMM*		

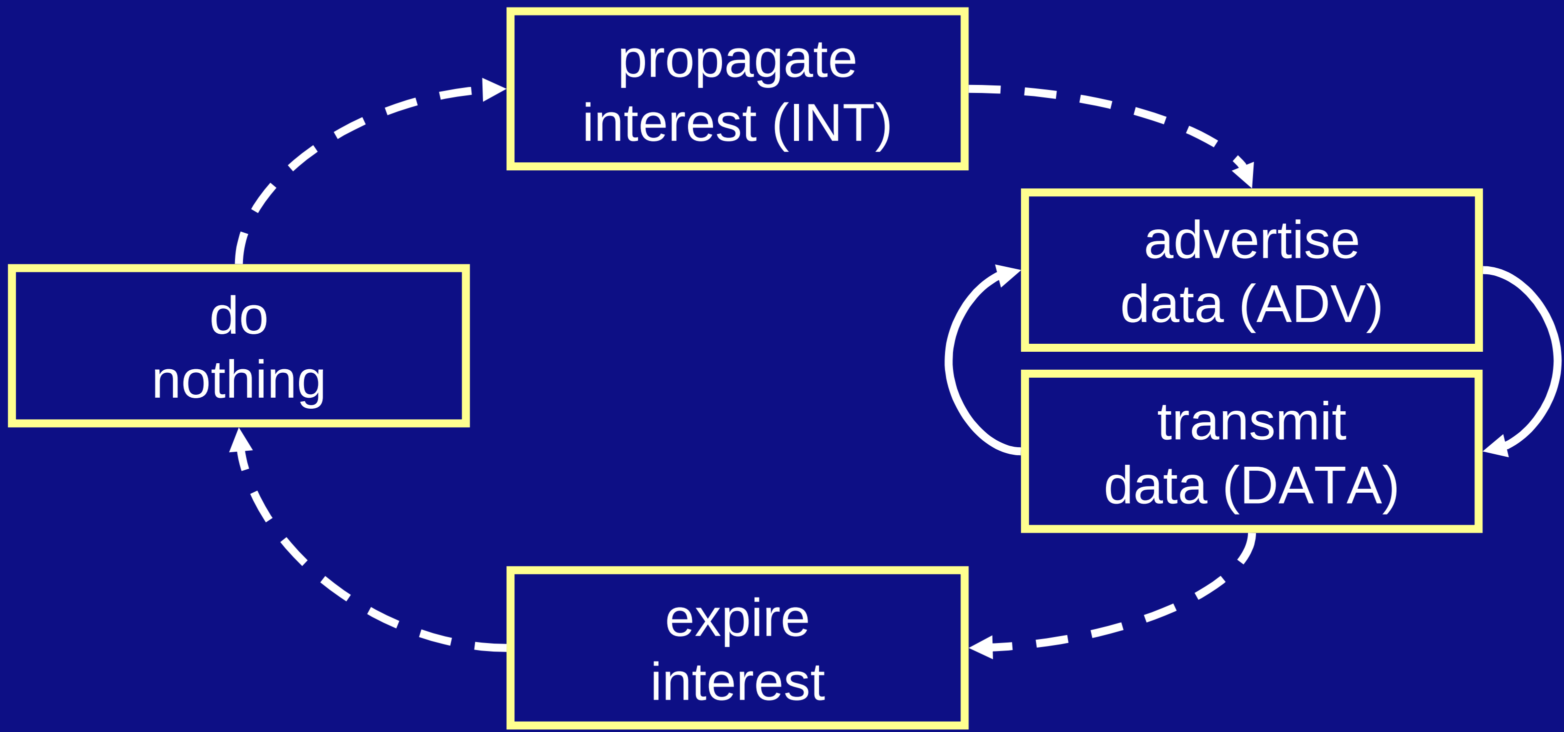
D3: Data-centric MAC & routing

- light-weight
- scalable
- energy-conserving
- robust

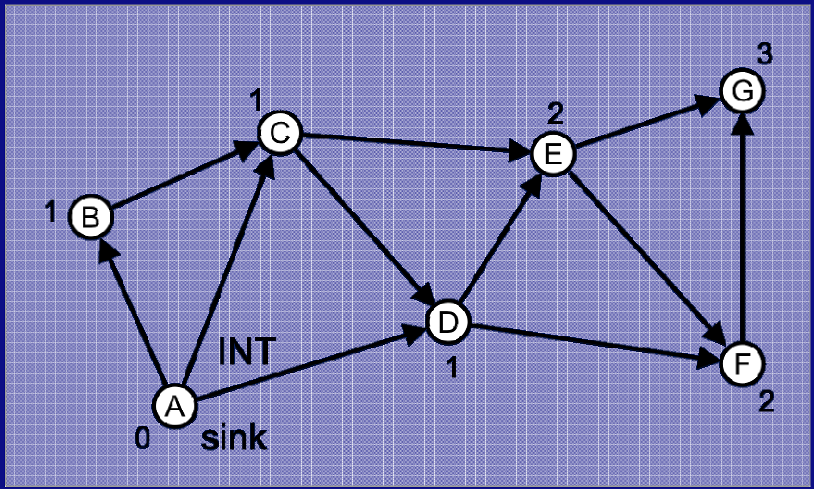
No central authority

The *data* is important, not the *node* it came from

D3 outline

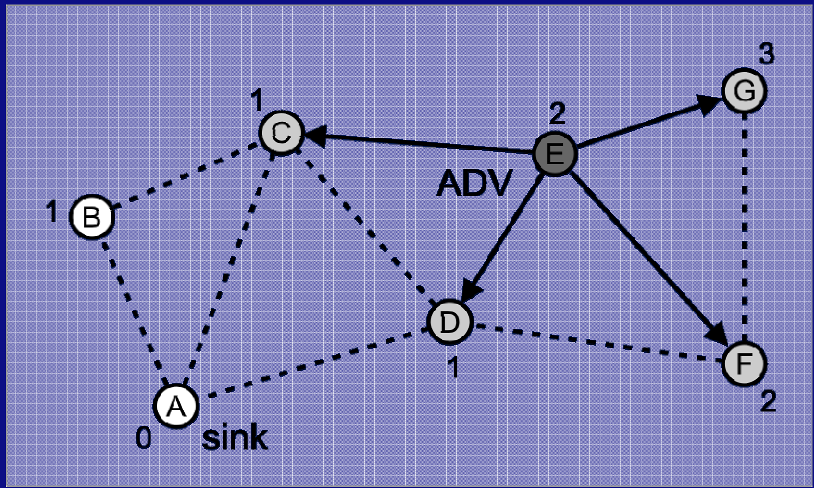

propagate
interest (INT)
advertise
data (ADV)
transmit
data (DATA)
expire
interest
do
nothing

Step 1: Interest propagation



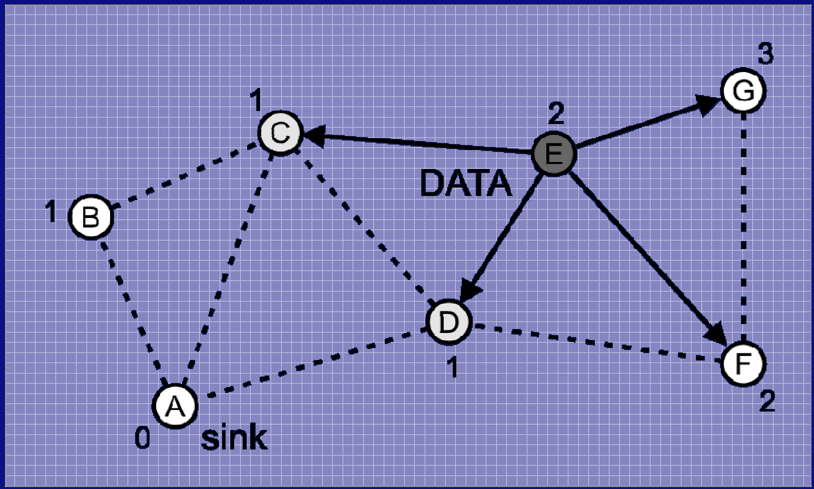
- ***Sink*** **sends** ***interests*** **to all nodes using** ***flooding***

Step 2: Data advertisement



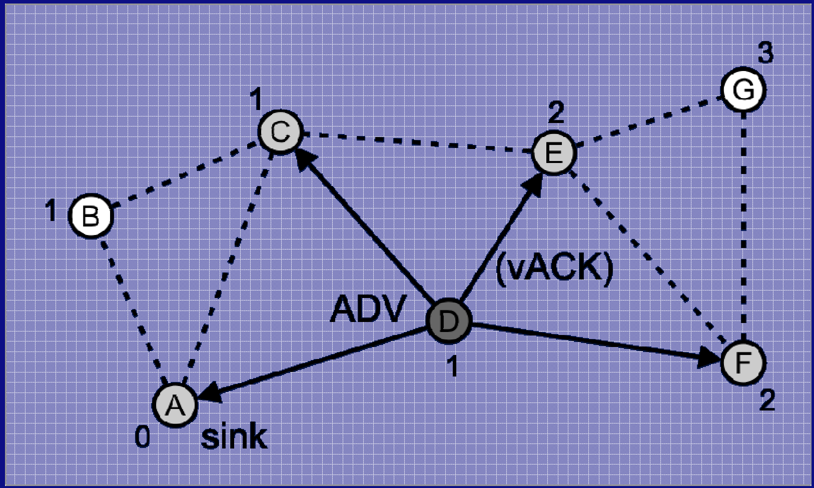
- *Sink* sends *interests* to all nodes using *flooding*
- **Node *advertises* it *will* send data using *broadcasting***

Step 3: Data transmission



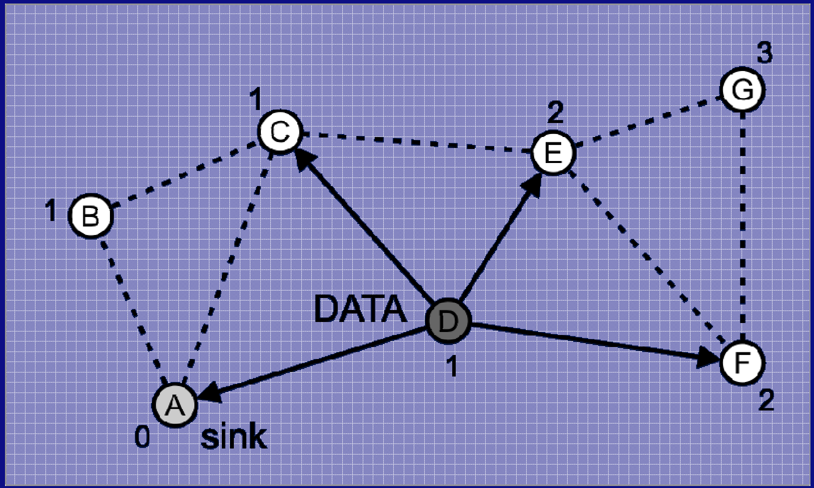
- *Sink* sends *interests* to all nodes using *flooding*
- Node *advertises* it *will* send data using *broadcasting*
- **Actual data is *broadcasted* to *interested* neighbors**

Step 4: Data advertisement revisited



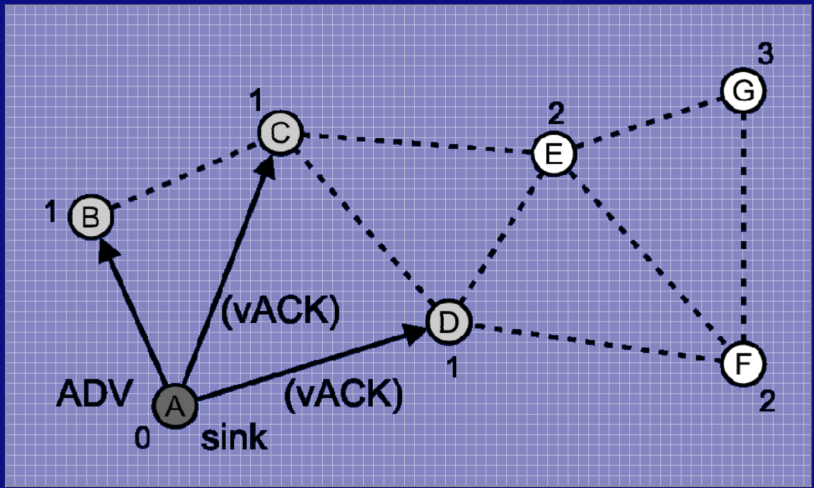
- *Sink* sends *interests* to all nodes using *flooding*
- Node *advertises* it *will* send data using *broadcasting*
- Actual data is *broadcasted* to *interested* neighbors
- **Subsequent advertisements are used to *acknowledge* and *delay* transmissions**

Step 5: Data transmission



- ***Sink*** **sends** ***interests*** **to all nodes using** ***flooding***
- **Node** ***advertises*** **it** ***will*** **send data using** ***broadcasting***
- **Actual data is** ***broadcasted*** **to** ***interested*** **neighbors**
- **Subsequent advertisements are used to** ***acknowledge*** **and** ***delay*** **transmissions**
- **The data is** ***forwarded*** **to the sink**

Step 6: Final data advertisement



- *Sink* sends *interests* to all nodes using *flooding*
- Node *advertises* it *will* send data using *broadcasting*
- Actual data is *broadcasted* to *interested* neighbors
- Subsequent advertisements are used to *acknowledge* and *delay* transmissions
- The data is *forwarded* to the sink
- **The sink *acknowledges* the reception of the data**

Assumptions

- No central authority → no central databases for administration of addresses
- Transmitting data advertisements is cheaper than transmitting actual data messages
- Duty-cycled CSMA/CA MAC scheme (e.g., S-MAC, T-MAC)
- The *data* is important, not the *node* it came from