Objectives:

1) Understanding different types of wireless networks

Readings:

WIRELESS SENSOR NETWORKS AND VEHICULAR NETWORKS

Outline

- A taxonomy of wireless networks
- Wireless sensor networks (WSN)
  - Hardware
  - Run time systems
  - Routing
  - Current standardization efforts
- Vehicular ad hoc networks (VANET)
  - 802.11p
  - Delay tolerant network routing

A Taxonomy of Wireless Networks

Classification:

- Needs for central coordination
- Nodal mobility
- Continuous connectivity
- Relay needed?

Design:

- Medium access control
- Routing
- Transport
- Service discovery, synchronization …

Coordination

- Centralized controlled vs. peer-to-peer (ad hoc/ infrastructureless) networks

WBANs

Cellular network

WiFi-direct

Satellite networks

WLANs

Vehicular-to-road side networks

Vehicular-to-vehicular network

Wireless sensor networks

Mobility

- Mobile vs stationary networks

WBANs

Cellular network

WiFi-direct

Satellite networks

WLANs

Vehicular-to-road side networks

Vehicular-to-vehicular network

Wireless sensor networks

Connectivity

- Continuous connectivity vs. intermittently connected

WBANs

Cellular network

WiFi-direct

Satellite networks

WLANs

Vehicular-to-road side networks

Vehicular-to-vehicular network

Wireless sensor networks

Network diameter

- Single-hop vs multi-hop networks

WBANs

Cellular network

WiFi-direct

Satellite networks

WLANs

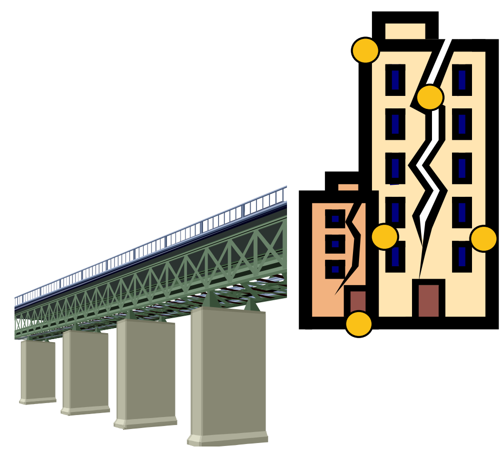
Vehicular-to-road side networks

Vehicular-to-vehicular network

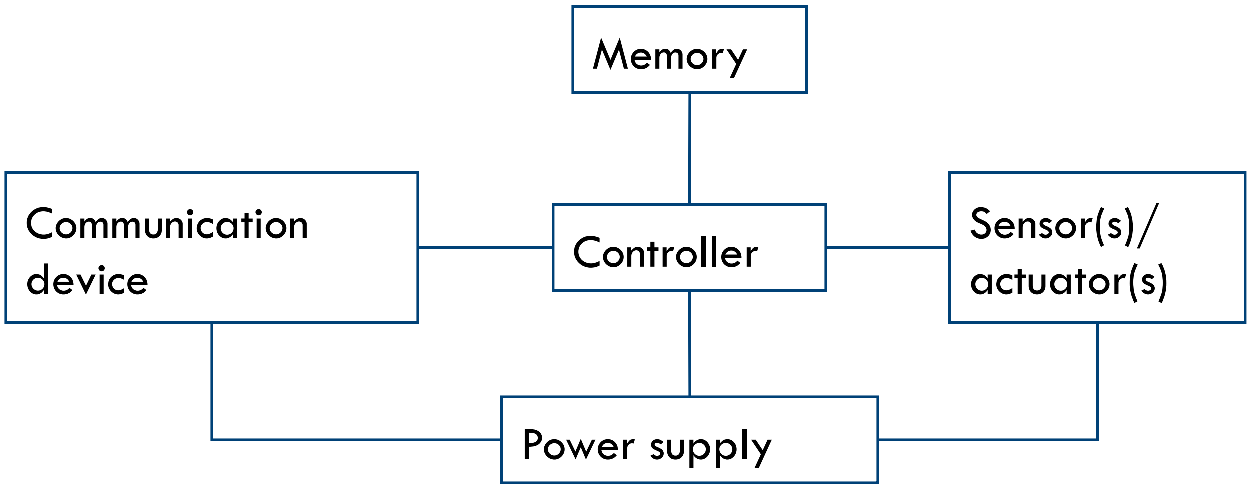
Wireless sensor networks

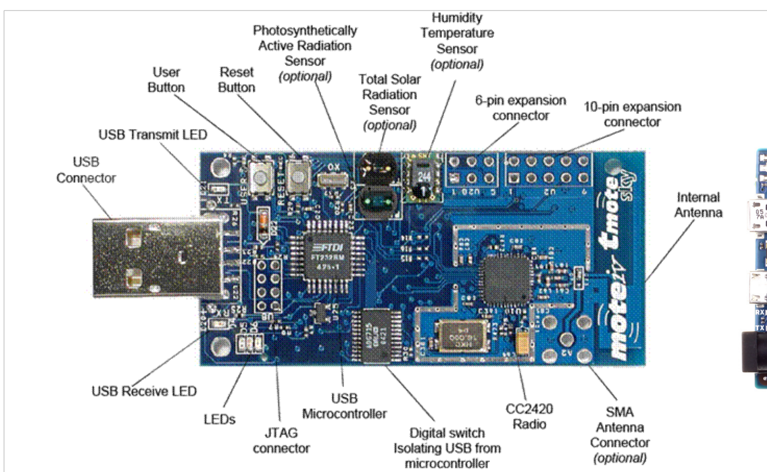
Wireless sensor networks (WSN)

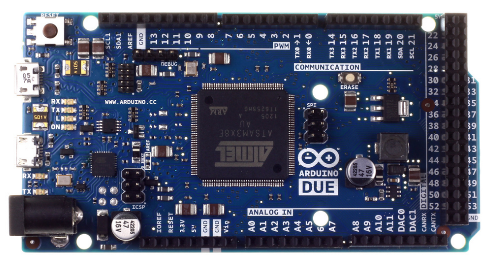
- “Stationary” + “continuous connectivity” + “multihop” + “infrastructureless” networks consisting of sensors and actuators *embedded into the environment*
  - Machine-to-machine communication
  - Data-centric
- Nodes are likely to be battery powered and have limited computation capability

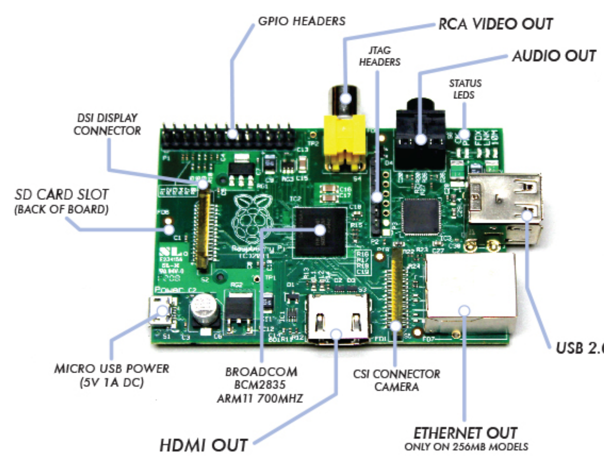


Sensor platform hardware









Processor

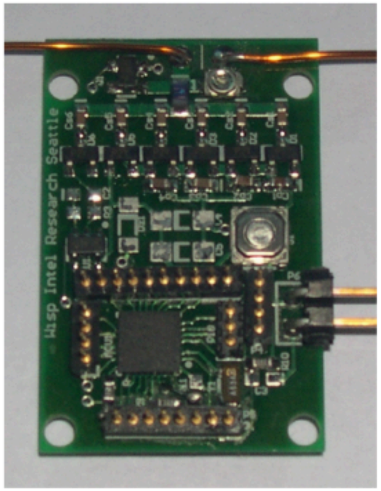
- MSP430
  - 16-bit RISC core, up to 4 MHz, versions with 2-10 kbytes RAM, several DACs, RT clock
  - Deepest sleep mode 0.3 μW
- Arduino Due
  - 32-bit Atmega AT91SAM3X8E, CPU clock@84MHz, 96KB SRAM
- Raspberry Pi
  - 32-bit ARM1176JZF-S processor, 700MHz, 512MB RAM

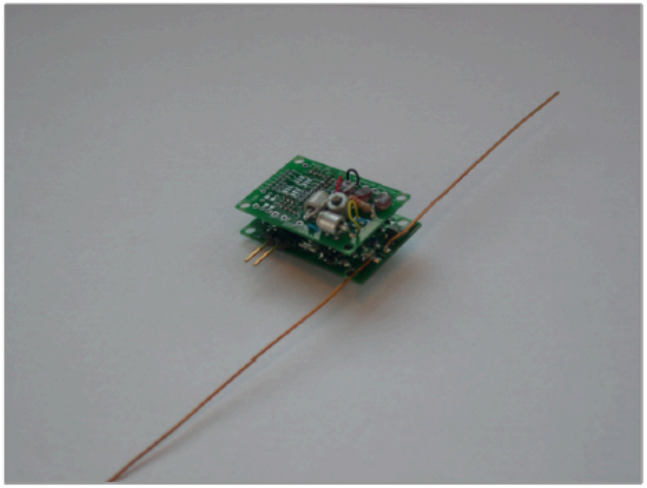
Radio

- A variety of radios can be used
  - Chipcon CC1000
    - Range 300 to 1000 MHz, programmable in 250 Hz steps
    - FSK modulation
    - Provides RSSI
  - Chipcon CC 2400
    - Implements 802.15.4 (Zigbee)
    - 2.4 GHz, DSSS + QPSK modulation
    - 250 kbps
  - WiFi
  - …

Power supply

- Battery or wall powered
- Energy scavenging
  - Solar power
  - Vibration
  - Harvesting RF power





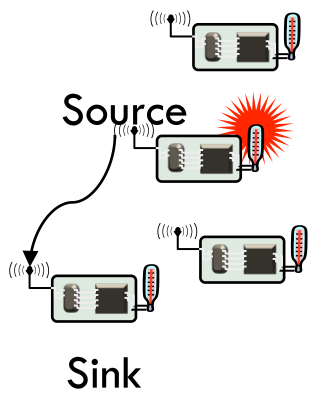
Intel WISP

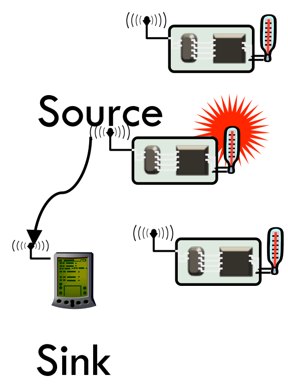
Run time environment

- Most sensor platforms are used for one single application
  - Customized run time environments, no OS
- Sensor network operating systems (OS):
  - TinyOS
  - Contiki OS
- Embedded Linux

Routing & transport layer in WSN

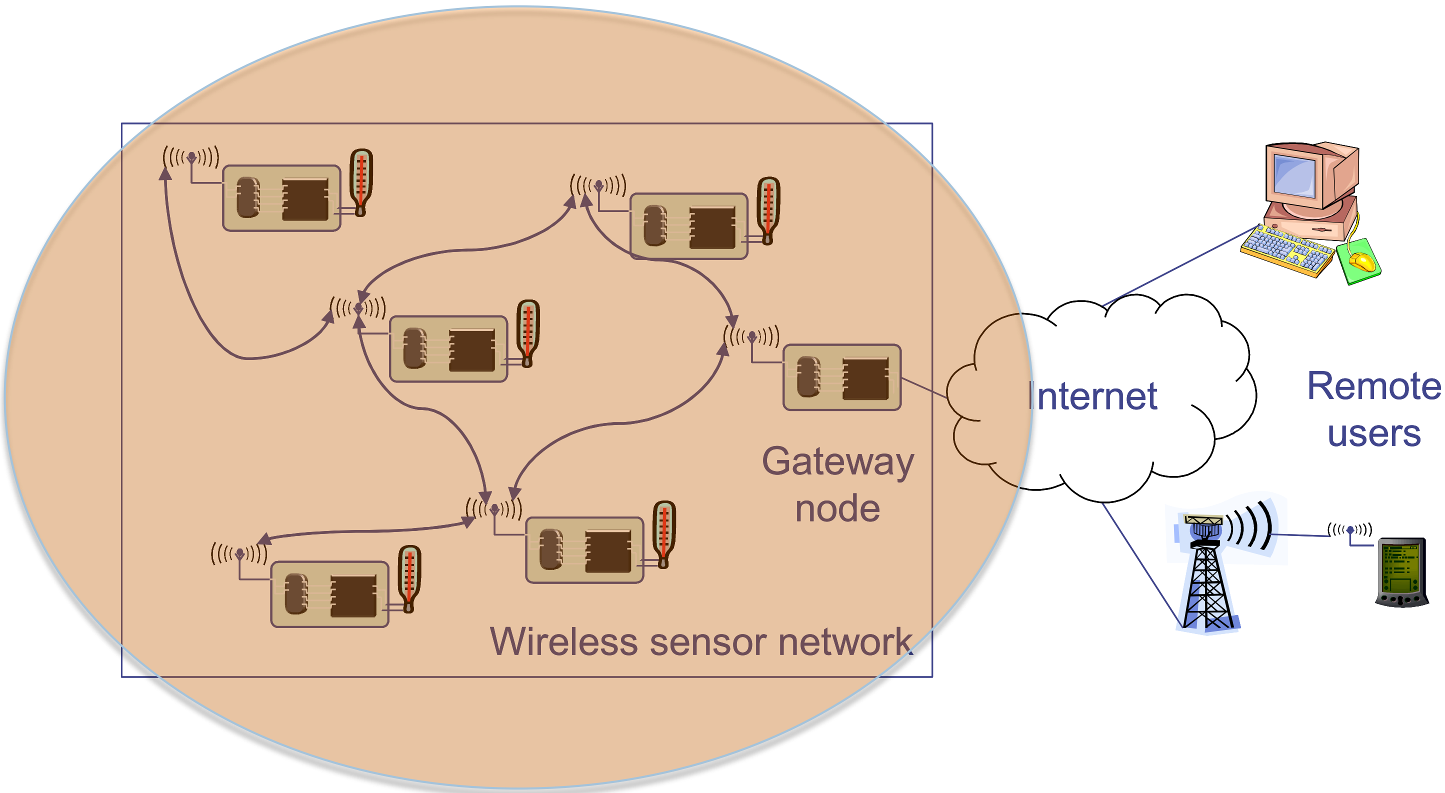
- Primarily broadcast (one to many) and converge-cast (many to one) with some one-to-one communication
  - Source: Any entity that provides data/measurements
  - Sink: Nodes that collect the data/measurements
- Types of traffic
  - Event based
  - Periodic (low-duty cycle) measurement
  - Command & control (one to one)





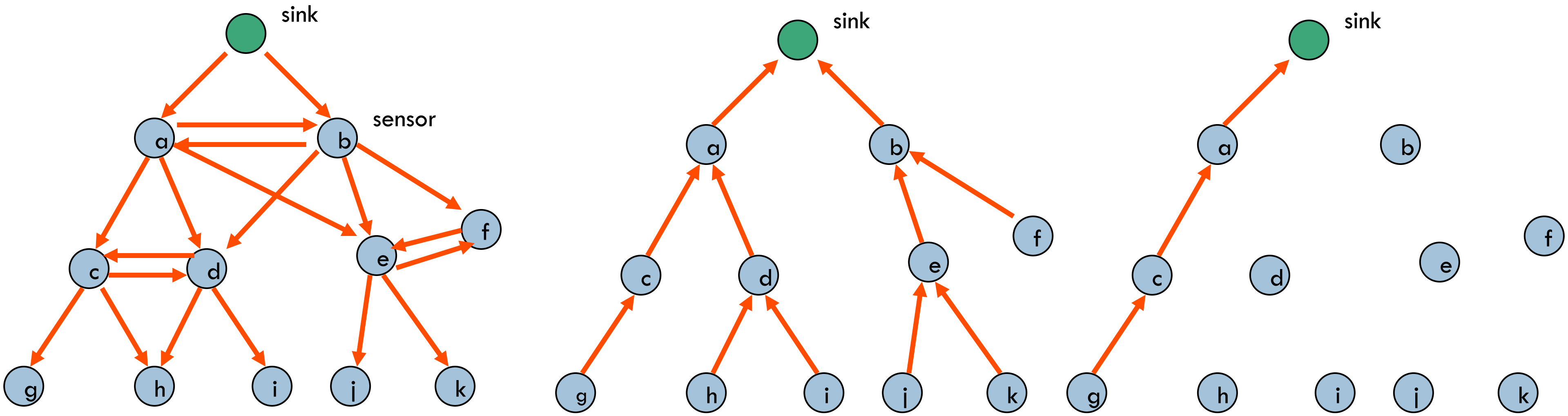
Sink may be mobile

Interfacing WSN with the Internet



Sink tree routing

- Suitable for periodic measurement gathering



Direct diffusion

- Event driven query processing
  - Data subscriber expresses interests; data publishers response of interested data – *publisher-subscriber*
  - (interestingly, some folks are trying to extend this concept into Internet under "named data networking (NDN)")

http://inrg.soe.ucsc.edu/~bruno/papers/x/directed_diffusion.pdf

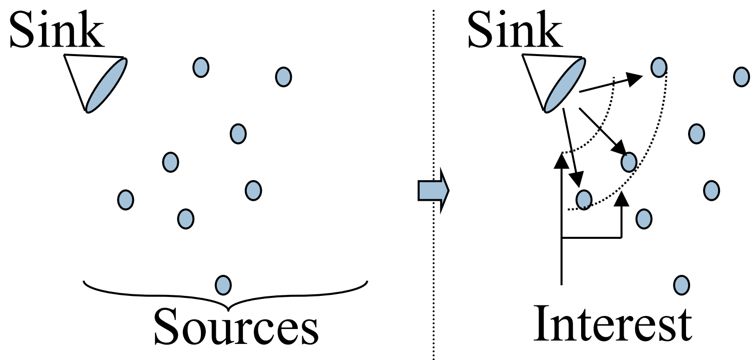
Data Naming

- Expressing an interest
  - Using attribute-value pairs
  - E.g.,

```
Type = Wheeled vehicle  // detect vehicle location
Interval = 20 ms        // send events every 20ms
Duration = 10 s         // Send for next 10 s
Field = [x1, y1, x2, y2]// from sensors in this area
```

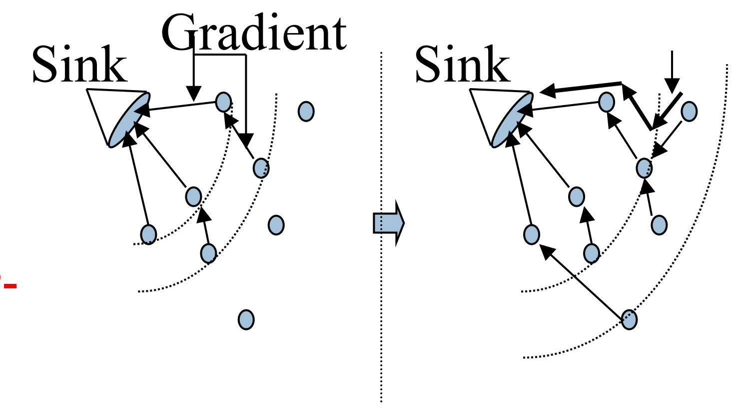
Setting up gradient

- Inquirer (sink) broadcasts exploratory interest, i_1
  - Intended to discover routes between source and sink
- Neighbors update interest-cache and forwards i_1
- Gradient for i_1 set up to upstream neighbor
  - No source routes
  - Gradient – a weighted reverse link
  - Low gradient → Few packets per unit time needed
- Bidirectional gradient if interests are flooded

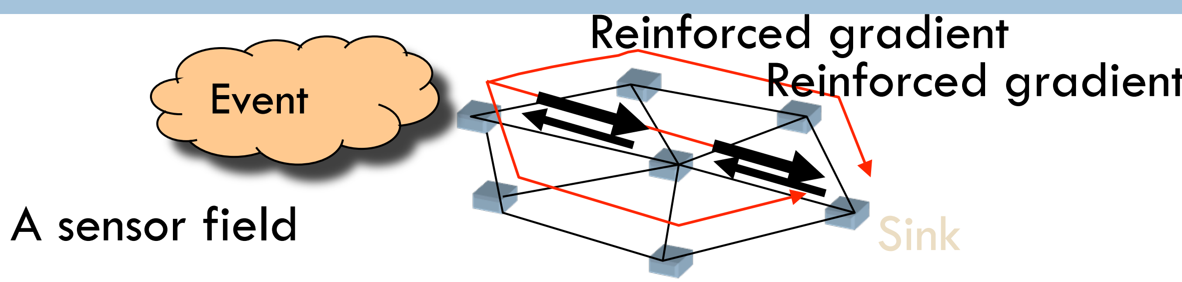


Event-data propagation

- Event e_1 occurs, matches i_1 in sensor cache
  - e_1 identified based on waveform pattern matching
- Interest reply diffused down gradient (unicast)
  - Diffusion **initially exploratory** (low packet-rate)
- Cache filters suppress previously seen data
  - Problem of bidirectional gradient avoided



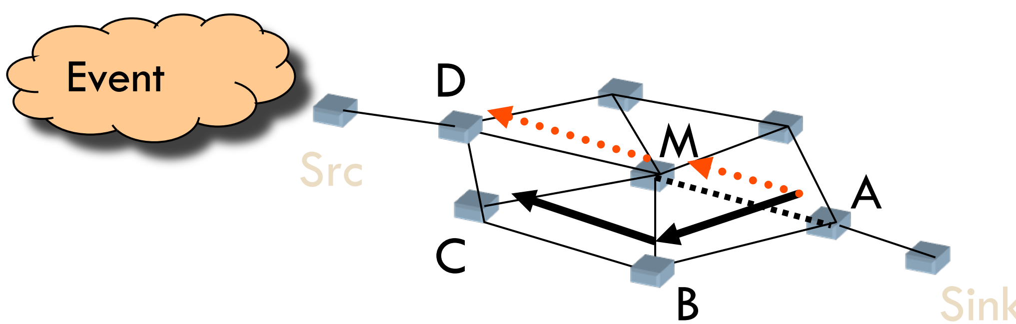
Reinforcement



- From exploratory gradients, reinforce optimal path for high-rate data download → Unicast
  - e.g. pick the neighbor who sent the last-seen data
  - By requesting higher-rate-i_1 on the optimal path
  - Exploratory gradients still exist – useful for faults

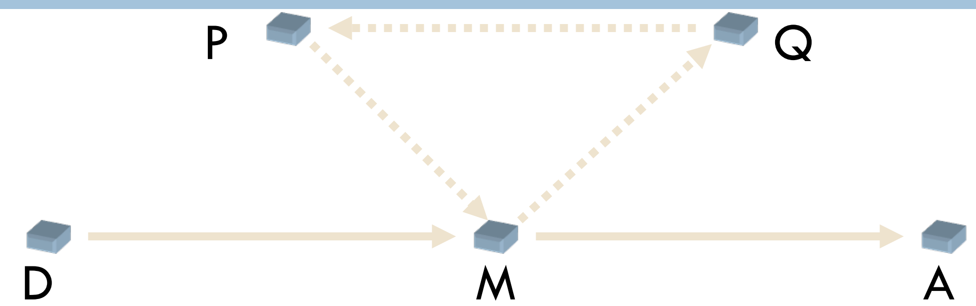
Path Failure / Recovery

- Link failure detected by reduced rate, data loss
  - Choose next best link (i.e., compare links based on infrequent exploratory downloads)
- Negatively reinforce lossy link
  - Either send *i1* with base (exploratory) data rate
  - Or, allow neighbor's cache to expire over time



<u>Link A-M lossy</u>
A reinforces B
B reinforces C …
D need not
A (–) reinforces M
M (–) reinforces D

Loop Elimination



- M gets same data from both D and P, but P **always** delivers late due to looping
  - M negatively-reinforces (NR) P, P nr Q, Q nr M
  - Loop {M → Q → P} eliminated
- Conservative negative reinforcement useful for fault resilience

6LoWPAN

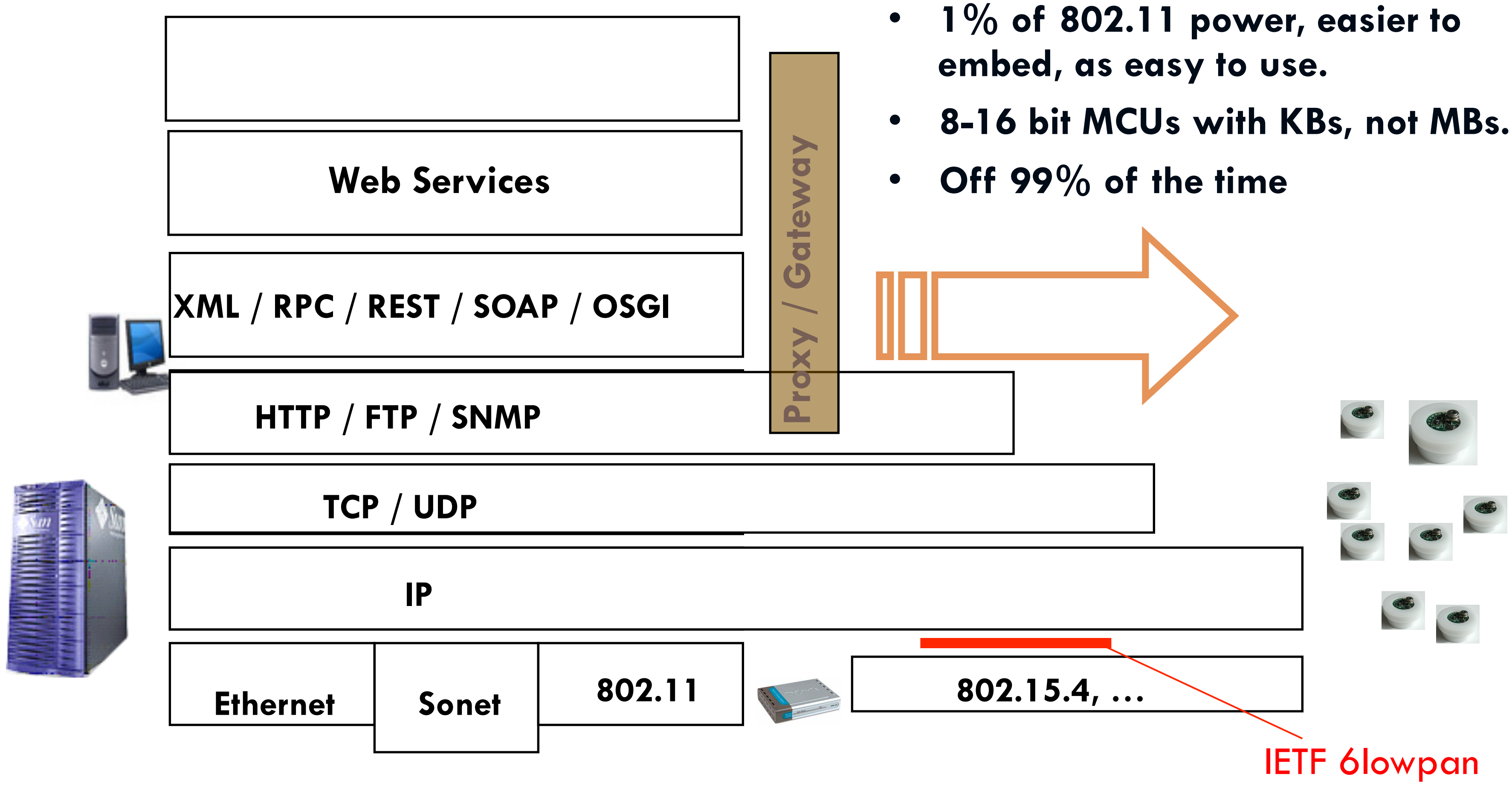
- Layer-2
- Supporting IPv6 over low power wireless personal area networks
  - Allow IPv6 packets to be sent & received over IEEE 802.15.4 based networks
  - Better interoperability

http://solomon.ipv6.club.tw/Course/ProtocolEngineering/archrock-6lowpan-tutorial.pdf

Adaptation layer

LoWPAN – 802.15.4

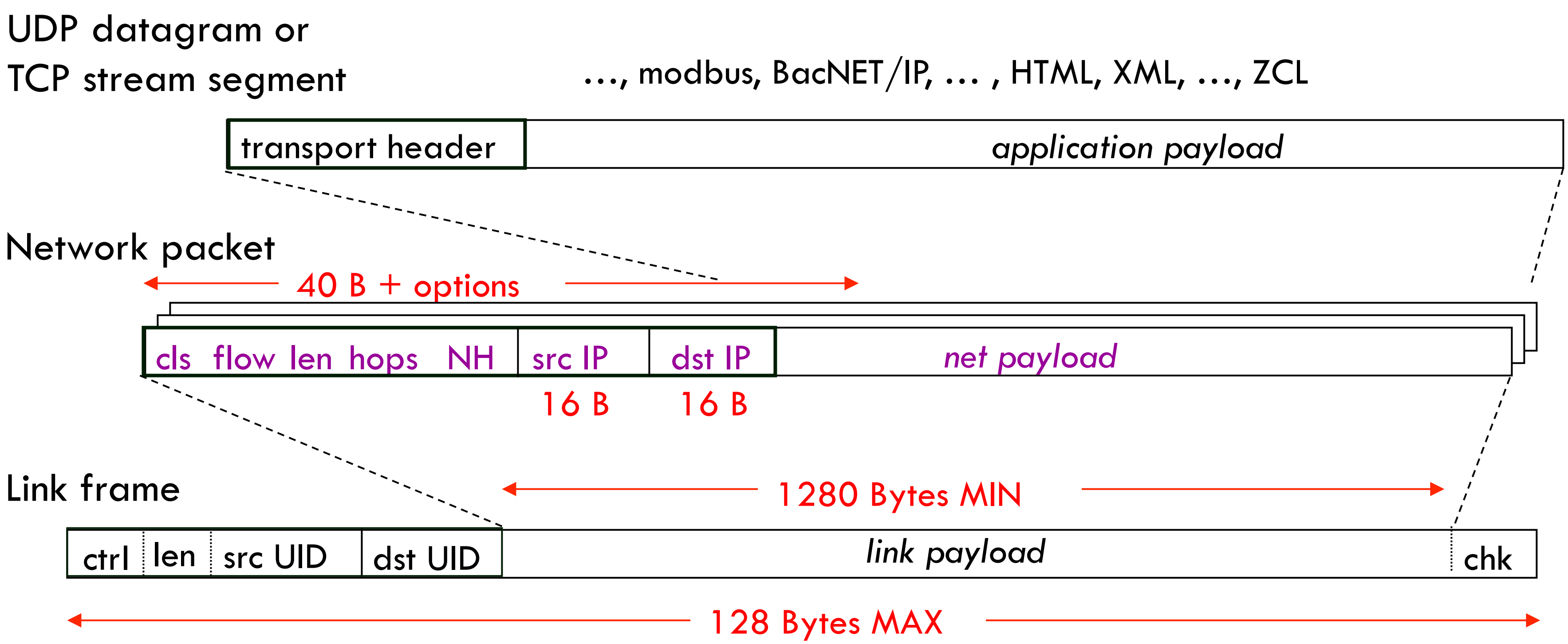
- **1% of 802.11 power, easier to embed, as easy to use.**
- **8-16 bit MCUs with KBs, not MBs.**
- **Off 99% of the time**



Challenges

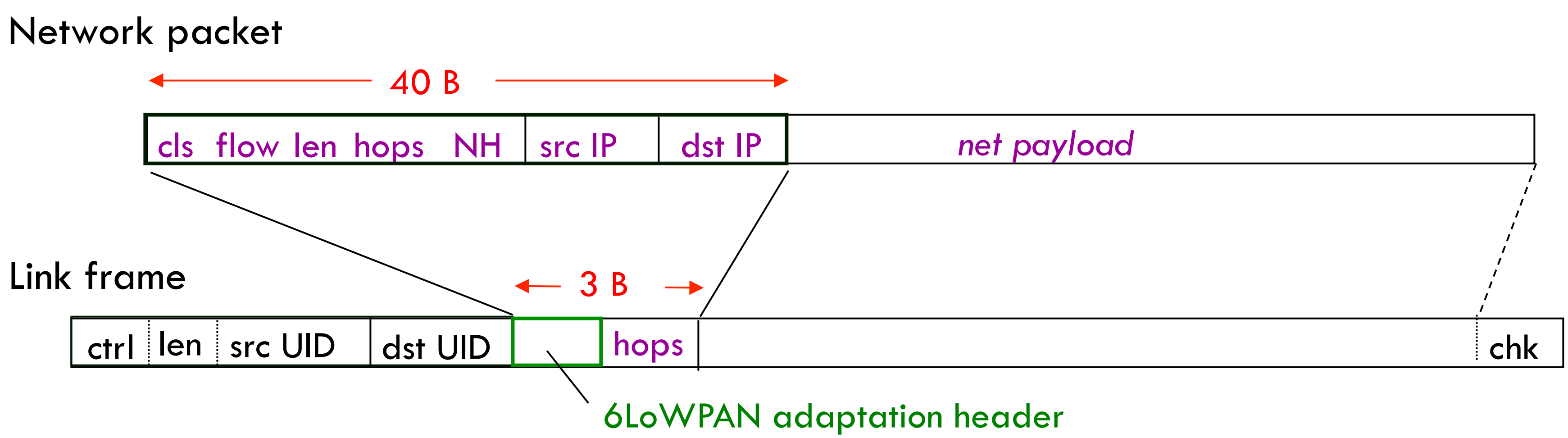
- Header
  - Standard IPv6 header is 40 bytes [RFC 2460]
  - Entire 802.15.4 MTU is 127 bytes [IEEE]
  - Small data payload
- Fragmentation
  - Interoperability means that applications need not know the constraints of physical links that might carry their packets
  - IP packets may be large, compared to 802.15.4 max frame size
  - IPv6 requires all links support 1280 byte packets [RFC 2460]
- Allow link-layer mesh routing under IP topology
  - 802.15.4 subnets may utilize multiple radio hops per IP hop
  - Similar to LAN switching within IP routing domain in Ethernet
- Allow IP routing over a mesh of 802.15.4 nodes
  - Options and capabilities already well-defines
  - Various protocols to establish routing tables

IP Header and payload



- Large IP Address & Header => 16 bit short address / 64 bit EUID
- Minimum Transfer Unit => Fragmentation
- Short range & Embedded => Multiple Hops

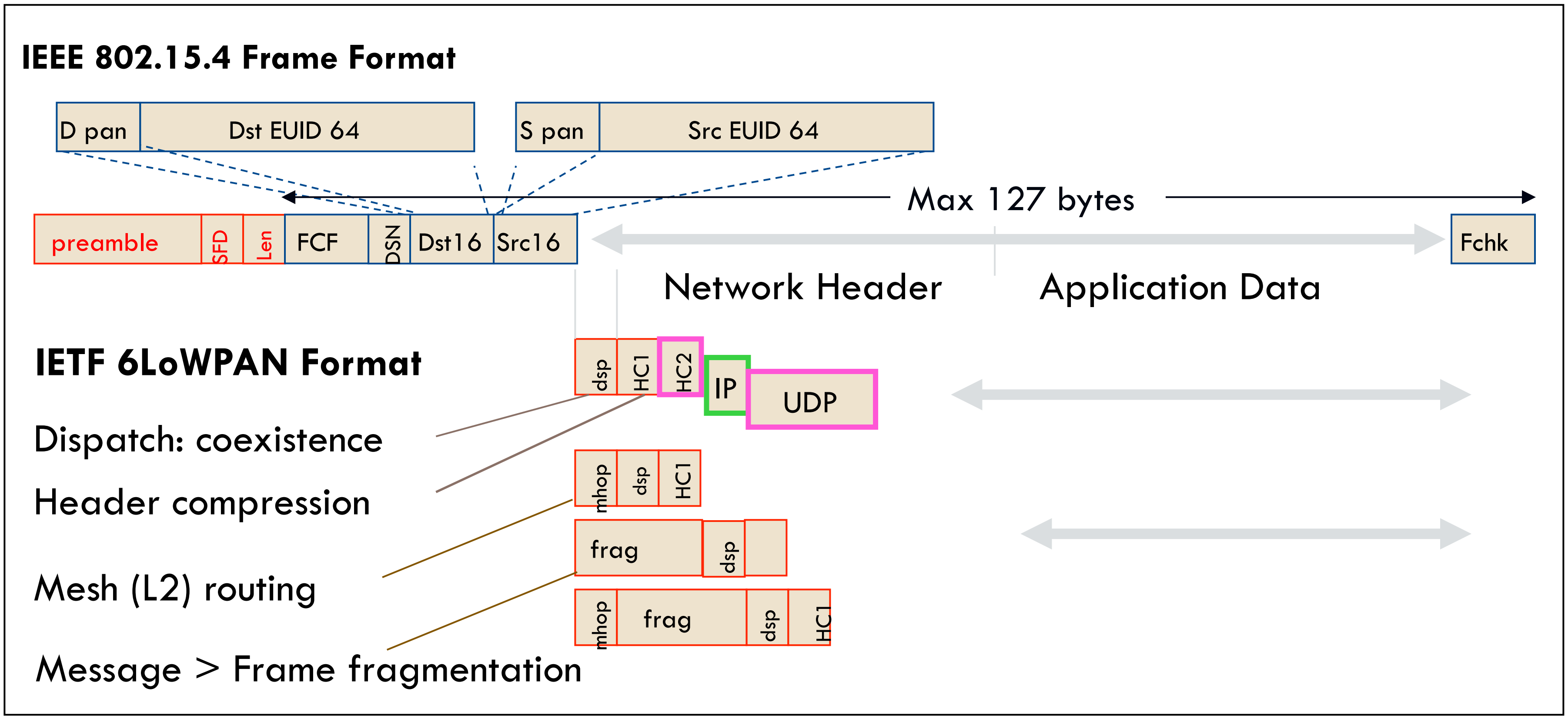
6LoWPAN – IP Header Optimization



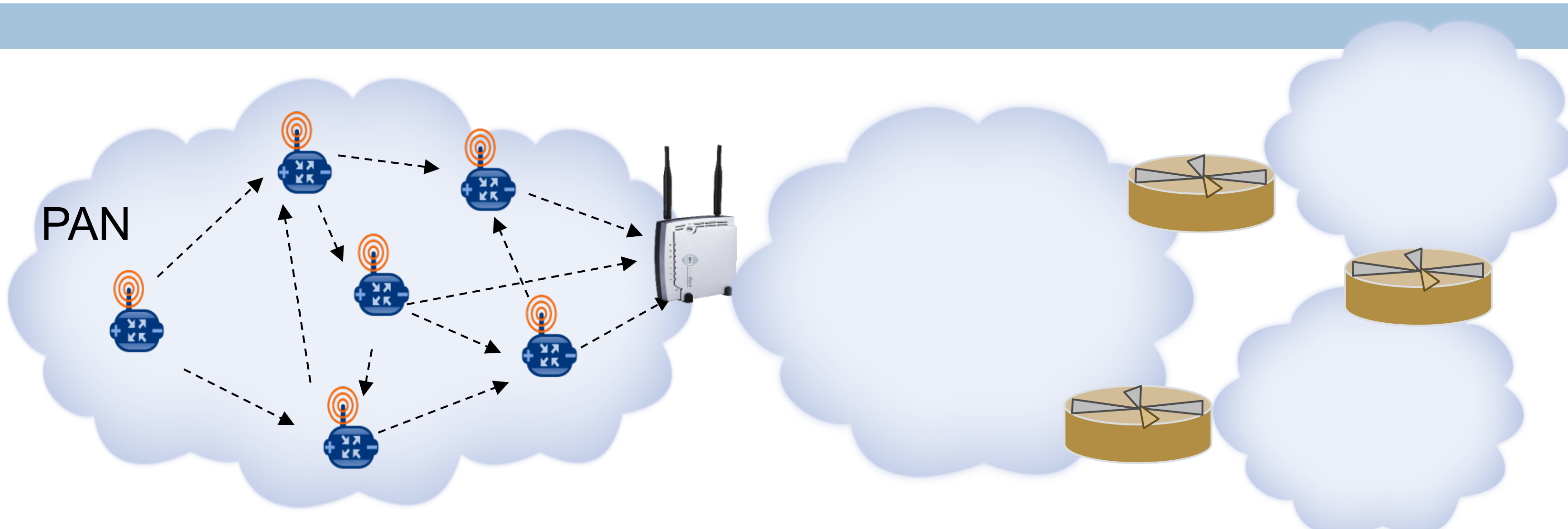
- Eliminate all fields in the IPv6 header that can be derived from the 802.15.4 header in the common case
  - Source address : derived from link address
  - Destination address : derived from link address
  - Length : derived from link frame length
  - Traffic Class & Flow Label : zero
  - Next header : UDP, TCP, or ICMP
- Additional IPv6 options follow as options

6LoWPAN Format Design

- Orthogonal stackable header format
- Almost no overhead for the ability to interoperate and scale.
- Pay for only what you use



Multi-Hop Communication

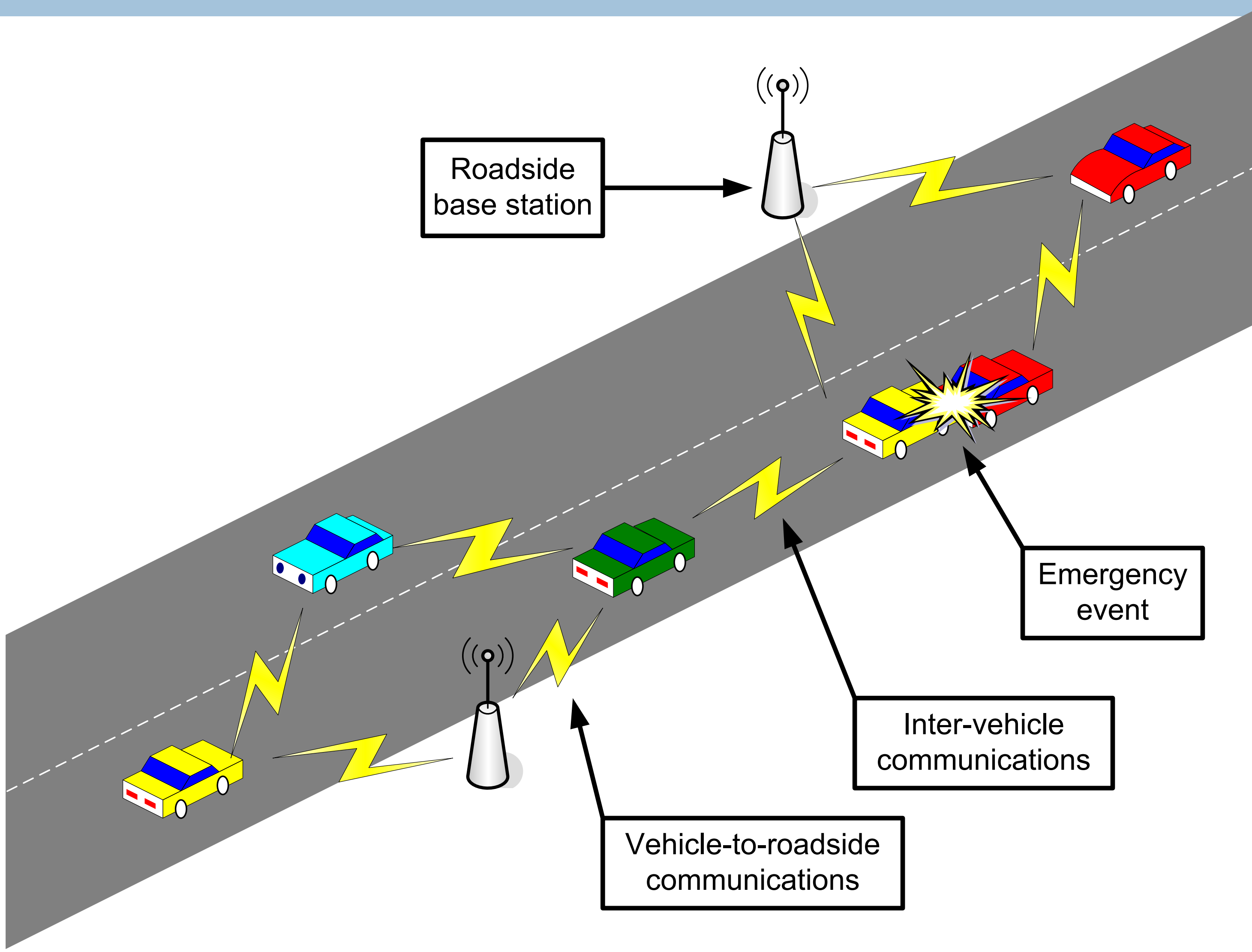


- Short-range radios & Obstructions => Multi-hop Communication is often required
  - i.e. Routing and Forwarding
  - That is what IP does!
- "Mesh-under": multi-hop communication at the link layer
  - Still needs routing to other links or other PANs
- "Route-over": IP routing within the PAN
- 6LoWPAN supports both

Wireless Vehicular Networks

- Vehicular-to-vehicular (V2V): infrastructureless + multihop + mobile + "intermittent connectivity"
- Vehicular-to-roadside: infrastructure + single hop + mobile + "intermittent connectivity"

Vehicular ad hoc networks (VANET)



Applications

- V2V
  - Single-hop notification: lane changing, automatic cruise control, collision warning
  - Multi-vehicle: traffic monitoring and accident alert
  - May be latency sensitive
- Vehicle-to-roadside
  - Accident alerting, congestion, high-speed tolling, mobile infotainment, location based services
  - (infrastructure not yet available)

Challenges & characteristics

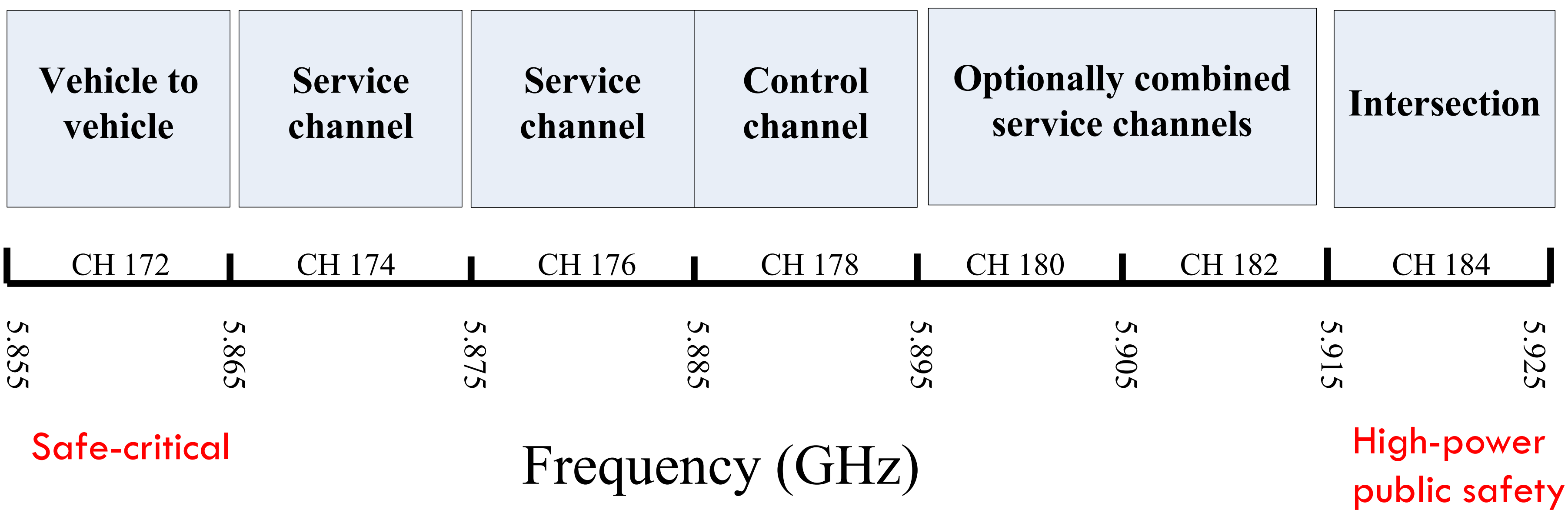
- Poor link quality (multipath, Doppler effects)
- Short-duration connectivity
  - Less so for traffic in the same direction
- Confined mobility (along the road way)
- Location dependent
  - Information pertain to a particular geographical area
- Availability of location information & “infinite” power supply

VANET Protocols

- DSRC/802.11p
  - Dedicated Short Range Communication (DSRC) was released in 2002 by the American Society for Testing and Materials (ASTM).
  - In 2003, the standardization moved to IEEE Forum and changed the name from DSRC to WAVE (Wireless Ability in Vehicular Environments), which was also known as 802.11p.

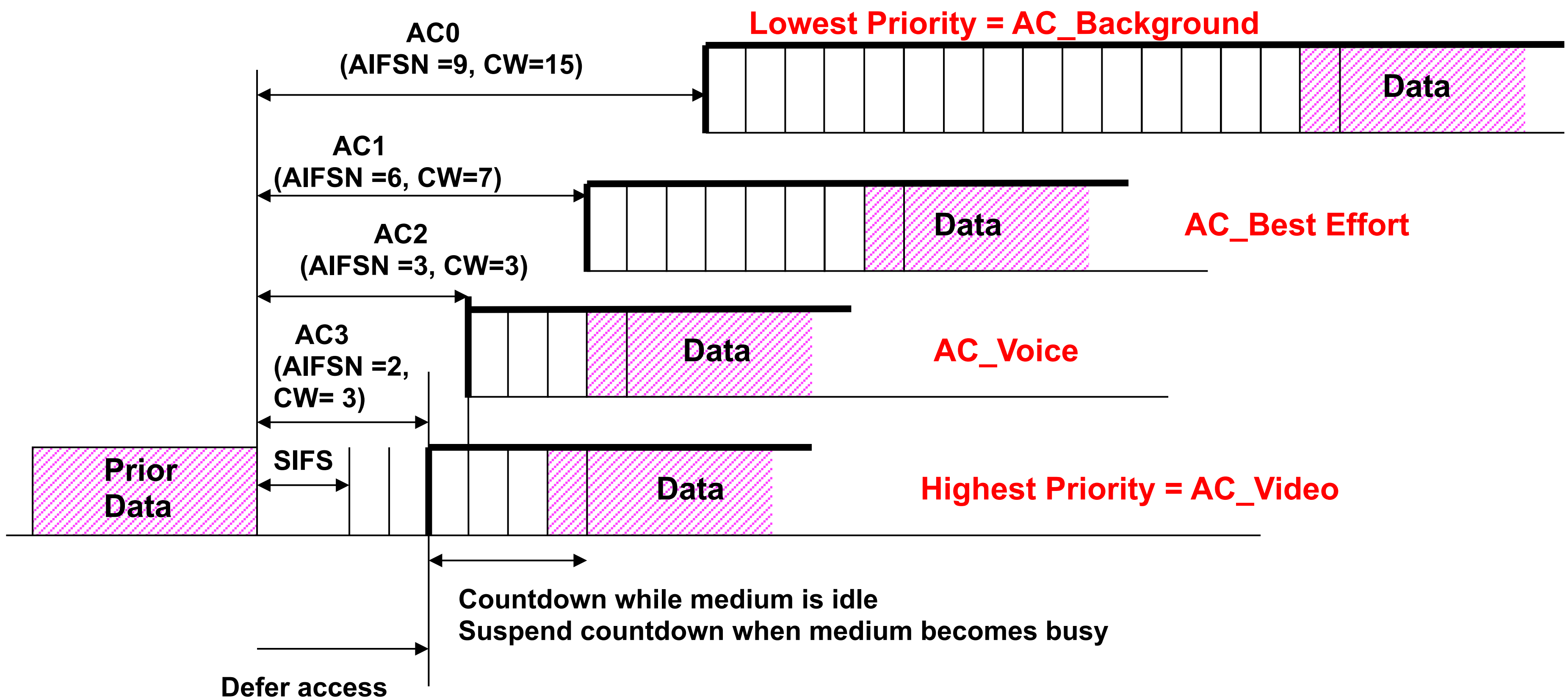
802.11p PHY

- The standard of 802.11p is based on IEEE 802.11a PHY layer and IEEE 802.11 MAC layer
  - A variation of OFDM modulation to combat multipath
  - Seven 10 MHz channels at 5.9GHz
  - one control channel and six service channels
  - Data rates are between 6 and 27 Mbps; up to 1000 meter range



802.11p MAC

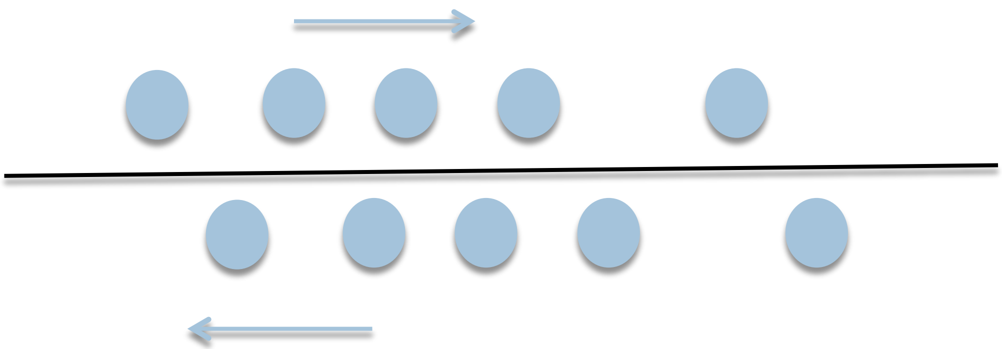
- CSMA/CA with different contention windows for different types of traffic
  - BK – background traffic; BE – best effort; VI – Video traffic; VO – voice traffic
  - AIFSN: arbitration inter-frame space number



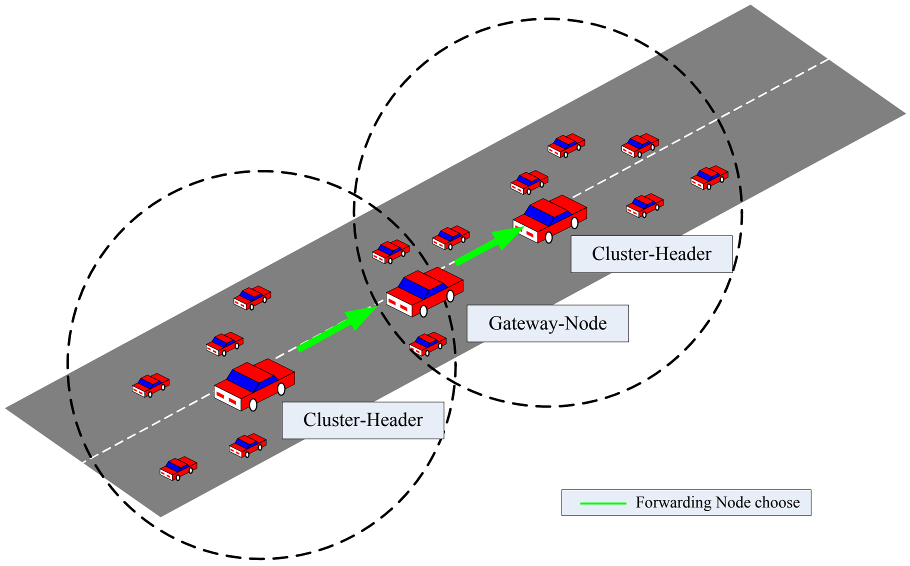
Routing in multi-vehicle V2V

- Design consideration:
  - Lifetime of routes likely to be short
  - Route establishment needs to be fast
- Broadcasting based information dissemination (stateless)
  - Detour route
  - Accident alert
  - Construction warning
  - …

Wireless broadcast "storm"

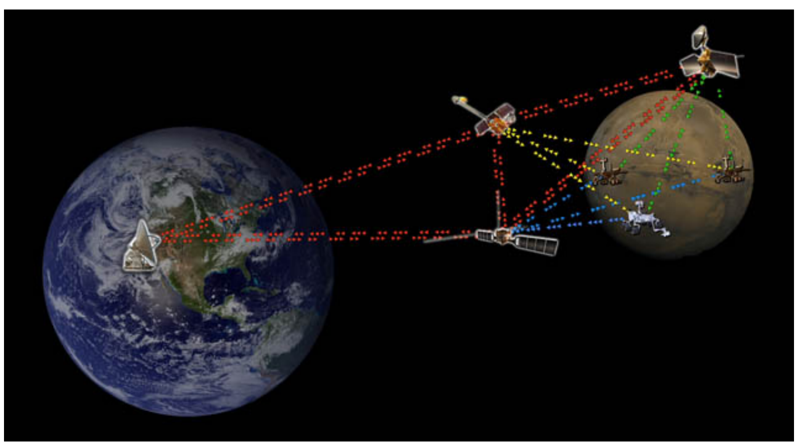


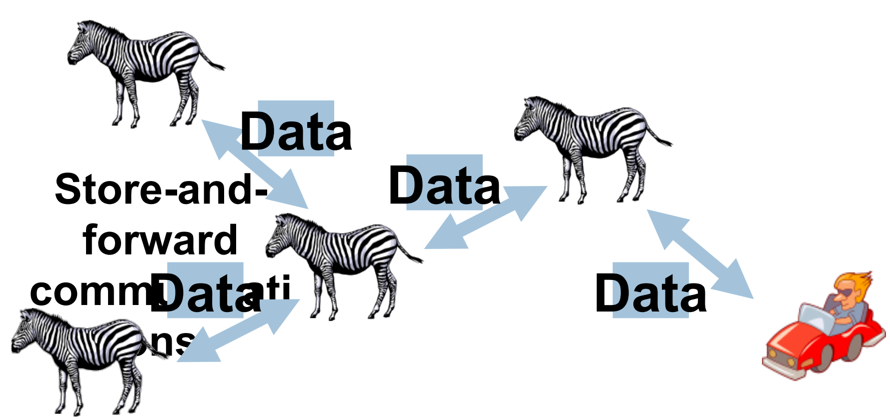
- Mitigation
  - Probabilistic forwarding
  - Location-based
  - Cluster-based



Routing in delay-tolerant networks (DTNs)

- DTNs are networks with intermittent connectivity (due to mobility)
  - Sparse vehicular networks
  - UAV networks
  - Human, animal networks
  - Inter-planetary networks
- Store-and-forward becomes store-carry-and-forward (“Data mule”, “pocket switch networks”)





DTN characteristics

- Opportunistic forwarding
- Long end-to-end latency
- Low end-to-end reliability
  - Some messages may never reach its destination
- "Topology" evolves over time as a function of mobility

DTN routing

- Single copy of messages
  - Find the “routes”
  - Deliver the message
- Multiple copies of the messages
  - Remember the famous six-degree of separation experiments?
  - Questions:
    - How many copies?
    - Who are the forwarders?
    - Termination of the messages once they are delivered

Some multi-copy based solutions

- Epidemic Routing (flooding): handover a copy to everyone
  - minimum delay under no contention
- Randomized Flooding: handover a copy w/ probability p
- Utility-based Flooding: handover a copy to a node w/ utility at least U_{th} higher than current
- Constrained Utility-based Flooding: like previous, but may only forward a bounded number of copies of the same message

Spray and wait

- Performance goals
  - significantly reduce transmissions by bounding the total # of copies/transmissions per message
  - under low traffic: minimal penalty on delay (close to optimal)
  - under high traffic: reduce the delay of existing flooding- and utility-based schemes thanks to less contention
- 2 phases:
  - "Spray phase": spread L message copies to L distinct relays
  - "Wait phase": wait until one of the L relays finds the destination (i.e. use direct transmission)

http://chants.cs.ucsb.edu/2005/papers/paper-SpyPso.pdf

Spray and Wait Variations

- Source Spray and Wait
  - Source starts with L copies
  - whenever it encounters a new node, it hands one of the L copies
  - this is the slowest among all (opportunistic) spraying schemes

- Optimal Spray and Wait
  - source starts with L copies
  - whenever a node with $n > 1$ copies finds a new node, it hands half of the copies that it carries
  - spreads the L copies faster than any other spraying scheme

Summary

- Discussed several variations of wireless networks
  - The characteristics of the networks (energy, connectivity, traffic pattern, infrastructure vs infrastructure-less, etc.) dictate the design of the network protocols
- The most prevalent networks remain to be single-hop, infrastructure-based networks
- We see some emerging applications for multihop and/or infrastructureless networks for smart metering, building management, V2V safety applications
- Machine-to-machine communication is likely to be the driver of wireless networking down the road