CSE 5469

Wireless Sensor Networks,
Mobile Ad Hoc Networks (MANETs),
Internet of Things

Bell's Law

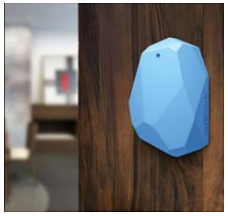
Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry.

G. Bell, *"Bell's Law for the Birth and Death of Computer Classes"*, Communications of the ACM, January 2008, Vol. 51, No. 1, pp. 86–94.

Bell's Law

Gen	Early Success	Moniker	Key Product	Key App	Human Interface
1	1955	Mainframes	Fortran	Tabulation	Batch Mode
2	1965	Symbolic Computing	Cobol	Accounting	
3	1975	Minicomputers	VAX 11/780	Scientific Computing	Interactive
4	1985	PC	IBM PC	Word Processing	
5	1995	Web Computing	Netscape	eCommerce	
6	2005	Smartphone Computing	iPhone	App Store	Touch
7	2015	???	???	???	???

Edge Devices: Things, Motes



beacons

thermostat

reorder button

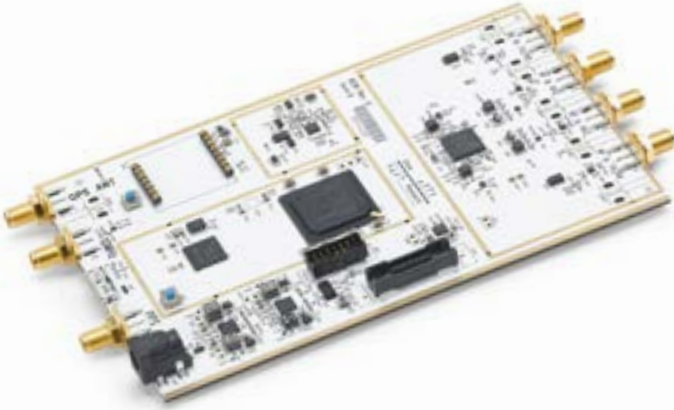
Arduino

motes

smart lock

Raspberry pi

health monitors



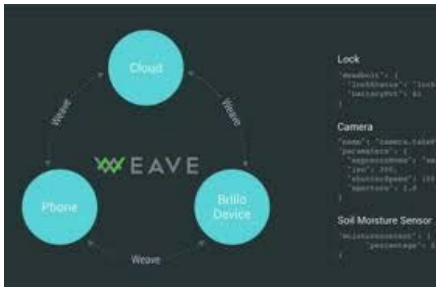
software defined radio

Edge Device Software Platforms*

TinyOS

eMote (.NET MF)

mbed OS



* ignoring gateway/cloud support platforms

IoT and WSN

- To a first approximation:

  WSN = IoT Devices + Mesh Network

Motivation:

- Number of devices per person growing sharply
- Number of interconnected devices growing too
- Moore's Law economic implication

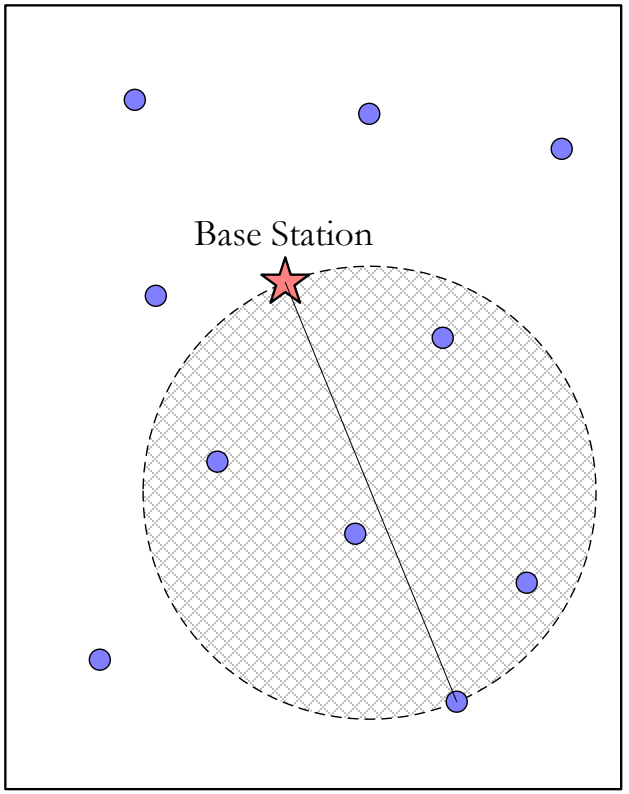
  $\Rightarrow$ rethink management and security

Why Mesh Edge Devices ?

- To increase available wireless capacity
- To increase lifetime of power constrained devices
- To compute in (edge) network, as opposed to at base station or in cloud

Understanding Wireless Capacity Constraints

With communication centralized via a Base Station, capacity for *n* devices is split *n* ways, i.e., O(1/*n*) scaling



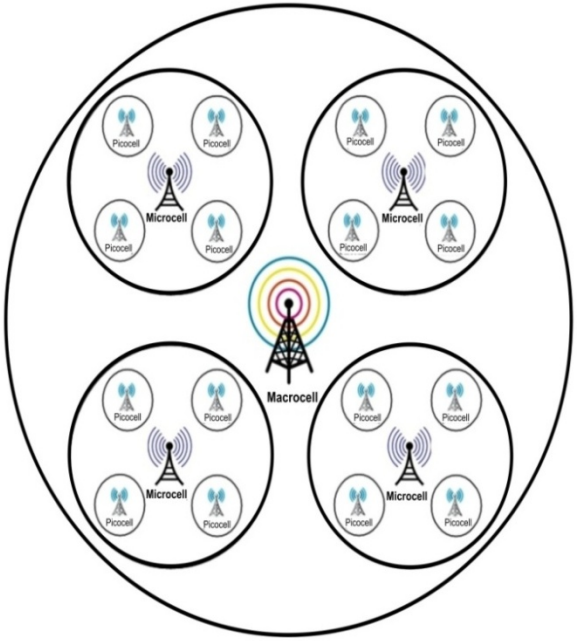
Standard solutions:

1. Increase number of Base Stations
2. Create hierarchy of Base Stations
3. Cooperation
4. Multi-hop mesh of devices

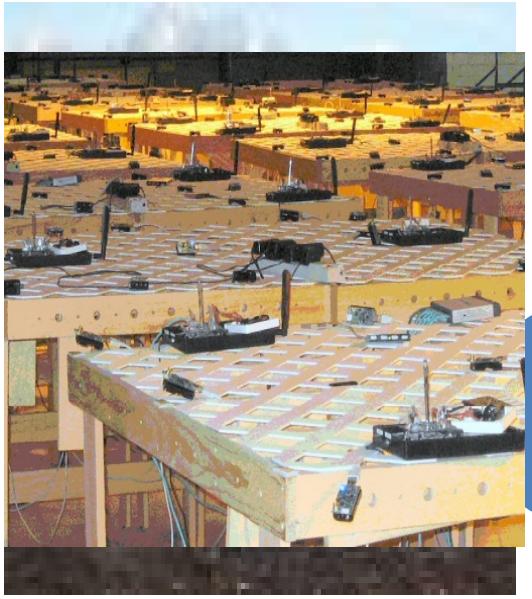
* capacity is the maximum achievable rate, over all node locations, all traffic patterns, and all protocols

Hierarchical Scaling

- Cellular infrastructure



- Wireless sensor networks



NES Kansei

- O(1) scaling in two tier hierarchies, if the number of base stations grows faster than $O\left(\sqrt{n}\right)$

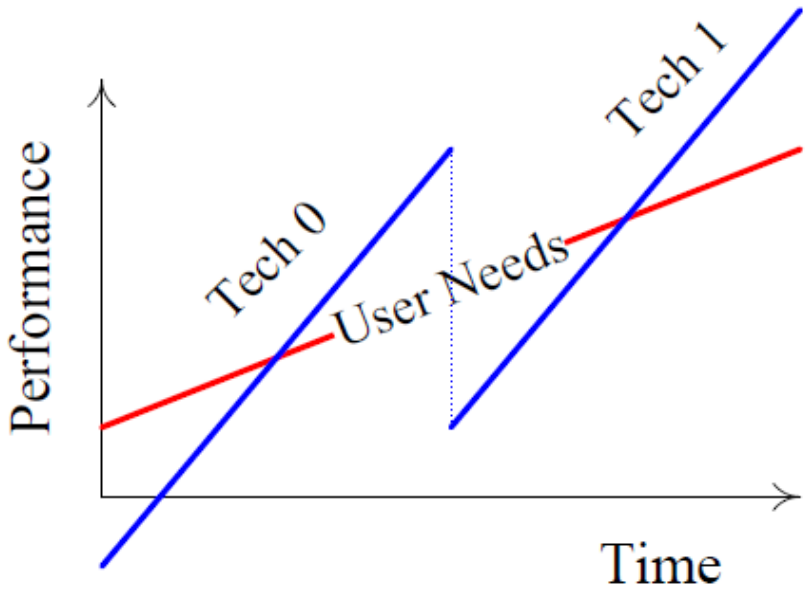
IoT and WSN: What's similar

Both are:

- Embedded/wearable: on us, in vehicles, in spaces
- Diverse radio and compute devices
- Typically updated in the field

- Downmarket from Smartphones
- Upmarket from passive RFID
- Christensen's theory predicts that the radical change will come from downmarket platforms

Christensen's Law

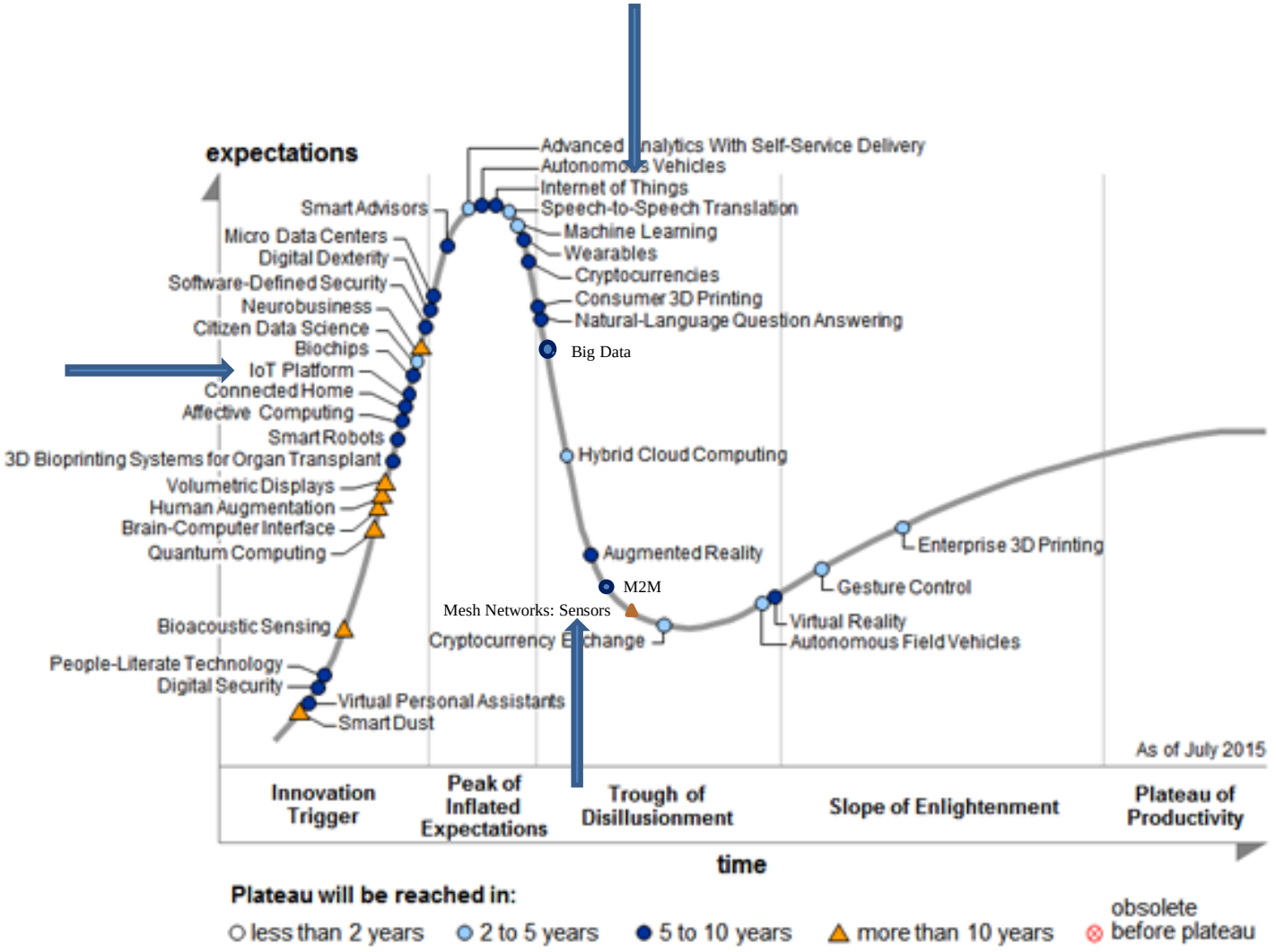


C. M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business Press; May 1, 1997, 225 pages.

IoT and WSN: Do they Differ?

- At different points in the Gartner Hype Cycle
- Several IoT device platforms assume wall power unlike WSN device platforms which operate on battery/energy harvesting
  - even if IoT devices communicate wirelessly, they tend to use high(er) power radios
- WSNs typically don't use TCP/IP networks; several don't depend on IP (v4 or v6) naming
  - several IoT platforms focus on application layer network protocols assuming the network is TCP/IP

Gartner Hype Cycle 2015

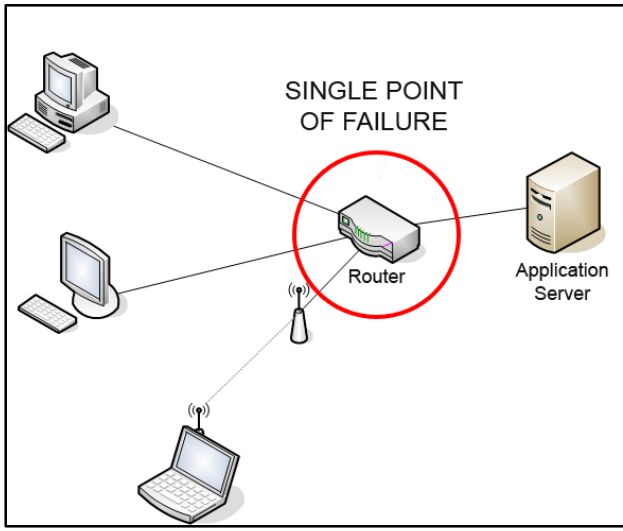


What we will Study

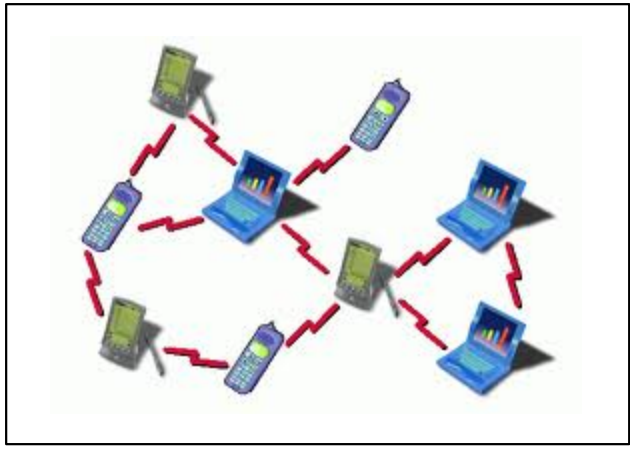
- Applications space
- Hardware and software platforms
  - Mote (programming labs in eMote MF on .NOW motes)
  - Smartphones platforms supporting low power operation
- Wireless capacity, transmission and link basics
  - Scalability theory, energy efficiency, metrics
- MAC, TimeSync, Routing, Wireless Reprogramming
- Robustness and Security at scale
  - Data driven machine learning

Mobile Ad hoc Networks (MANETs)

- Peer to peer networks offer lesser rigidity than in the internet
- Let's now add mobility to the equation
  - MANETs are untethered peer to peer networks
  - An OLD area… over the last 20 years, billions spent on MANET R&D, yielding many protocols (DSR, AODV, DSDV, OLSR) and radio platforms
- Edge devices not only sense, but are in control and actuation loop



versus



Infrastructure-free Mobile Networks Struggling with Scaling

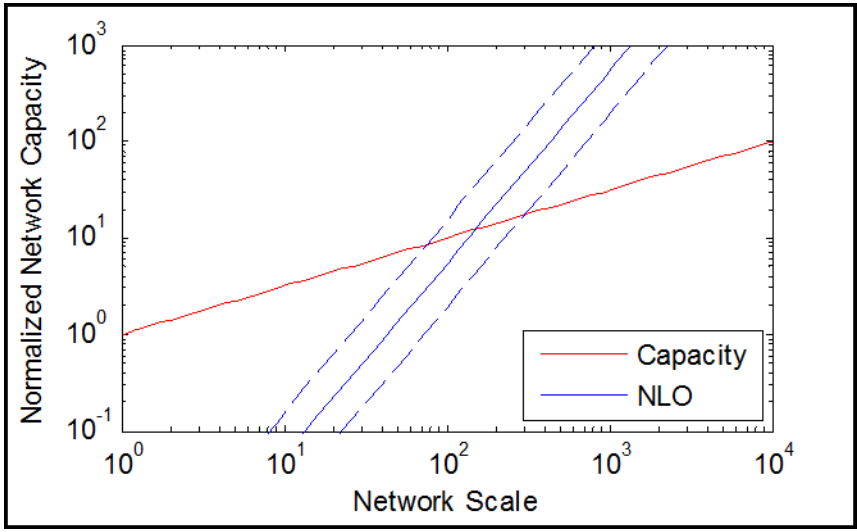
State of art

AODV, Dymo, NDN, etc. can scale in simulation to many 1000 nodes

The surprise

After spending several B$, largest infrastructure-free MANET fielded by DoD is not quite 100 nodes !

Scaling Walls



E.g.: Overhead vs Capacity

What will we Study

- Scaling walls
- Network architecture for scalable, heterogenous MANETs
- Application specific network patterns (ASNPs)
  - Scalability of ASNPs

Andreesen's Postulate

Software is Eating the World

While much of this thesis is reinventing software services (cf. Uber), it applies to reinventing devices !

- $\Rightarrow$ Increased programmability, even at lower layers
- $\Rightarrow$ Software Defined Networking (SDN) for wireless
- $\Rightarrow$ Network Virtualization for wireless

How the Edge Wireless SDN Differs

Capacity limits & mobility prevent ongoing global state snapshots as basic "waist"

- neighborhood waist

Separating data plane from control plane in desirable in wireline networks with data traveling at many Gbps

- not so for wireless SDN !
  - wireless links are much slower than wireless links
    $\Rightarrow$ data plane latency is not a primary consideration
  - conversely, substantial growth in compute resources
    $\Rightarrow$ hop by hop application specific packet recomputation feasible

What we will Study

- What does virtualization and software defined networking mean for IoT/WSN/MANETs ?
- How social network concepts apply ?
- Physical layer programmability and security
  - NI SDR platform

Grading Plan

- Class participation 15%
  (incl. presentations)
- Class assignments 25%
- Project 60%

Projects

- eMote implementation
  - network pattern routing, wireless reprogramming,
- eMote security OS support implementation
  - Symmetric or Asymmetric
- SDR experiments at PHY layer
  - Channel reciprocity, Configuration space programmability
- Smartphone and hybrid smartphone-mote hacking design
  - Power reduction, energy efficiency
  - Close to the metal OS

Projects

- Robustness method design and analysis
  - Synthetic data generation of sensor data
  - Spurious data rejection techniques
- Machine Learning and Sensing Design
  - Human-Animal classifiers
  - Dreese thermal data model
  - STEM education experiments with motes
- Scalable MANET protocol design
  - Coexistence of ASNPs (local designs for stability and scalability)
- SDR motes?
- Related interests that you have (discuss these with me)

Book References

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- Wireless Sensor Networks: Deployments and Design Frameworks. By Elena Gaura, Michael Allen, Lewis Girod, et al. Springer 2010.
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- Principles of Embedded Networked Systems Design. By William Kaiser and Greg Pottie
- Wireless Communications & Networks, 2nd Edition. By William Stallings. ISBN: 0131918354