Ch.1 Introduction

Wireless Sensor Networks

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Introduction (1)

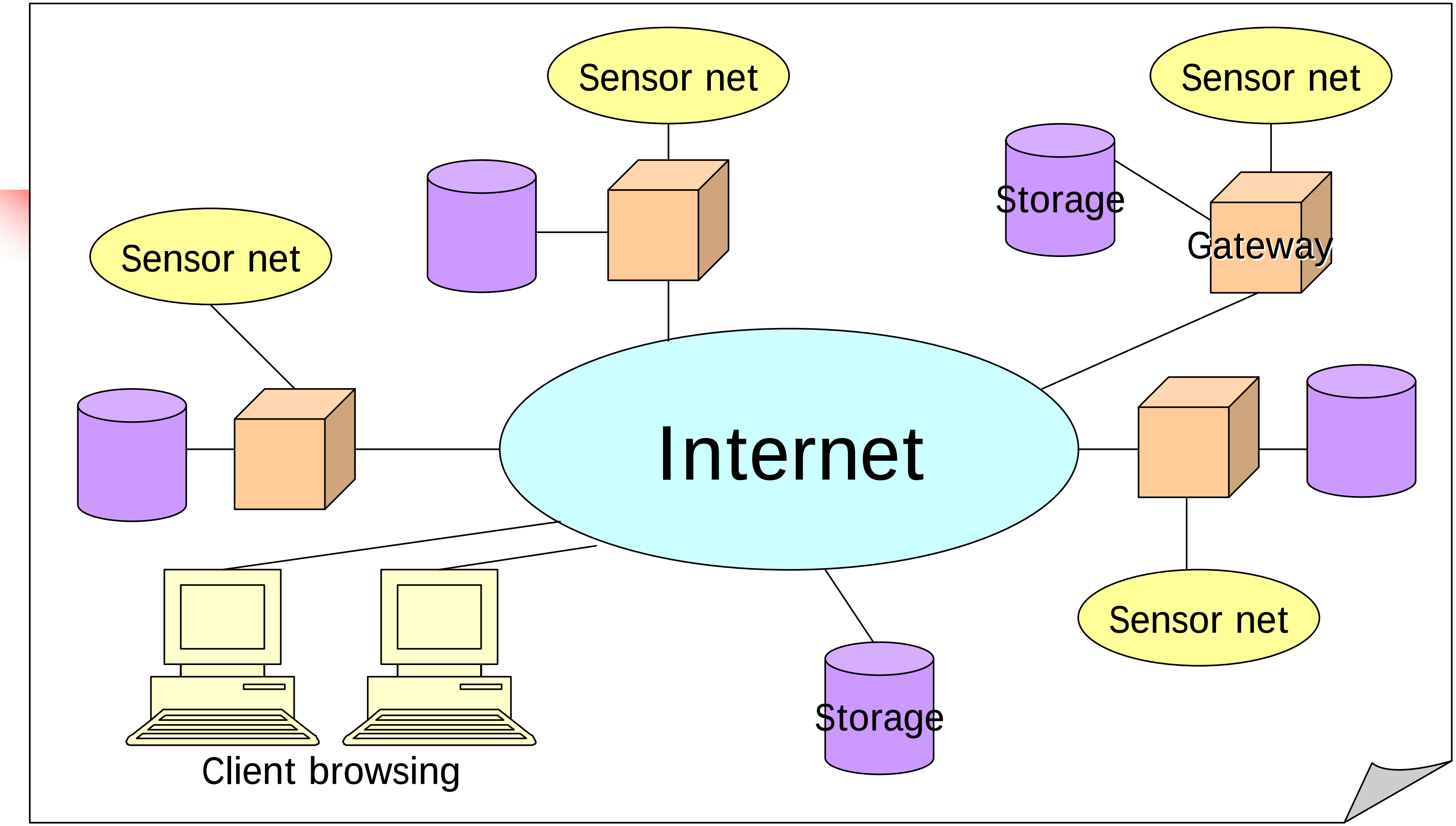
- A new generation of massive-scale sensor networks suitable for a range of commercial and military applications is brought forth by
  - Advances in MEMS (micro-electromechanical system technology)
  - Embedded microprocessors

Introduction (2)

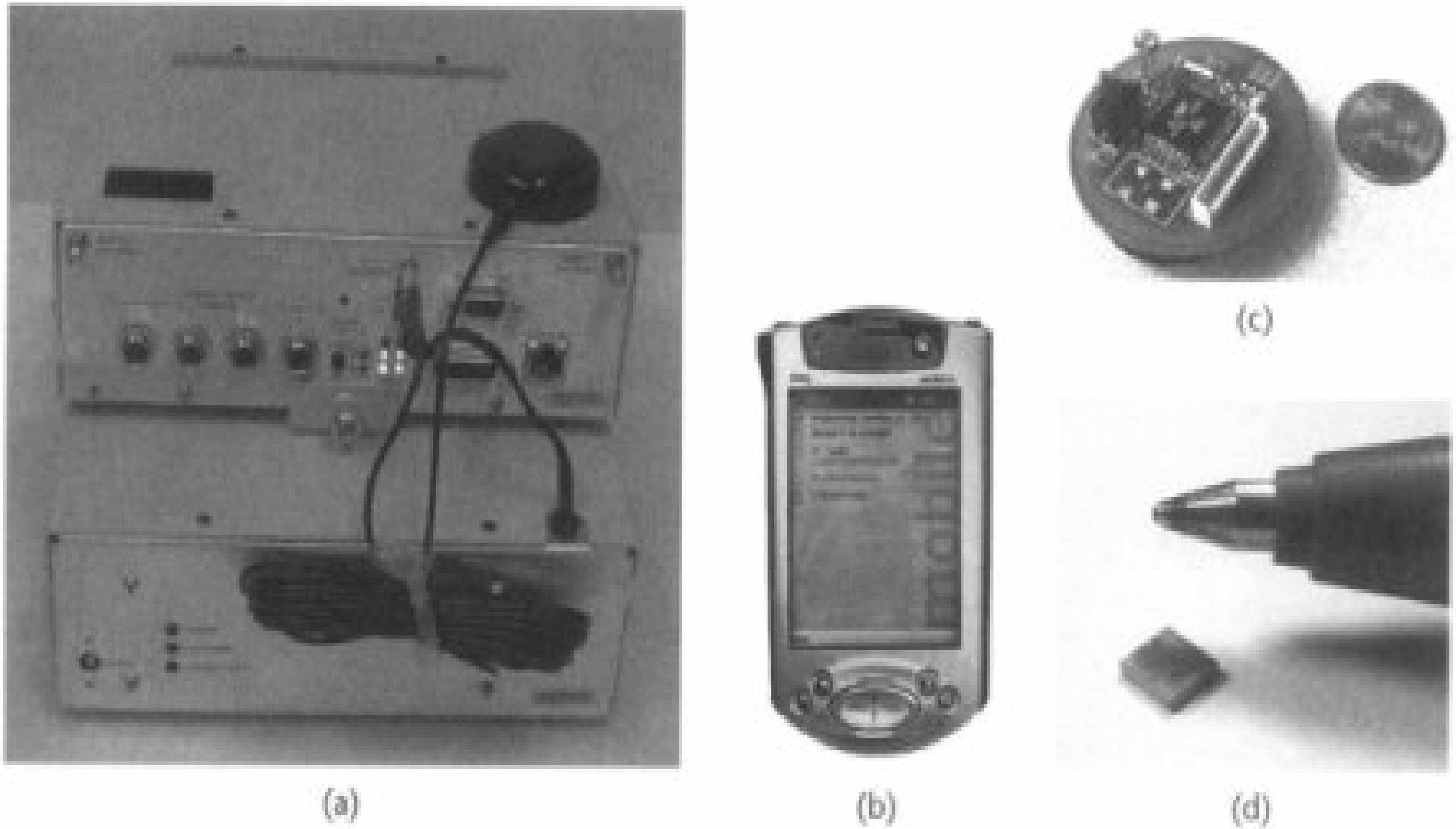
- Tiny, cheap sensors may be literally sprayed onto roads, walls, or machines, creating a digital skin that senses a variety of physical phenomena of interest.
  - Monitor pedestrian
  - Vehicular traffic in human-aware environments
  - Intelligent transportation grids
  - Report wildlife habitat conditions
  - Detect forest fires to aid rapid emergency responses
  - Track job flows and supply chains in smart factories

Constraints

- Finite on-board battery power
- Limited network communication bandwidth



Sensor networks significantly expand the existing Internet into physical spaces. The data processing, storage, transport, querying, as well as the internetworking between the TCP/IP and sensor networks present a number of interesting research challenges that must be addressed from a multidisciplinary, cross-layer perspective.



Samples of wireless sensor hardware: (a) Sensoria WINS NG 2.0 sensor node; (b) HP iPAQ with 802.11b and microphone; (c) Berkeley/Crossbow sensor mote, alongside a U.S. penny; (d) An early prototype of Smart Dust MEMS integrated sensor, being develped at UC Berkeley.

Comparison of the four sensor

	WINS NG 2.0 Node	iPAQ with 802.11 and A/D Cards in Sleeve	Berkeley MICA Mote	Smart Dust
Parts cost	$100s	$100s	$10s	<$1
Size (cm^3)	5300	600	40	0.002
Weight (g)	5400	350	70	0.002
Battery capacity (kj)	300	35	15	(Less)
Sensors	Off-board	Microphone & light sensors integrated, others off-board	Integrated on PCB: Acceleration, temperature, light, sound	MEMS sensors to be integrated
Memory	32MB RAM, 32MB flash	64MB RAM, 32MB flash	4KB RAM 128KB flash	(Less)
CPU	Hitachi SH4	StrongARM, XScale	ATmega 103L	(Less powerful)
OS	Linux	WinCE or Linux	TinyOS	(smaller)
Processing capability	400 MIPS/1.4 GFLOPS	240 MIPS	4 MIPS	(Less)
Radio range	100m	100m	30m	(Shorter)

Communicating VS Computing

- It is well known that communicating 1 bit over the wireless medium at short range consumes far more energy than processing that bit.
- For the Sensoria sensors and Berkeley motes, the ratio of energy consumption for communication and computation is in the range of 1,000 to 10,000.
- Thus, we should try to minimize the amount and range of communication as much as possible.

Challenges

- Limited hardware: Each node has limited processing, storage, and communication capabilities, and limited energy supply and bandwidth.
- Limited support for networking: The network is peer-to-peer, with a mesh topology and dynamic, mobile, and unreliable connectivity.
- Limited support for software development: The tasks are typically real-time and massively distributed, involve dynamic collaboration among nodes, and must handle multiple competing events.

Advantages of Sensor Networks

- Energy Advantage: by the multihop topology and in-network processing
- Detection Advantage: SNR is improved by reducing average distances from sensor to source of signal, or target.
- Robustness
- Scalability

Energy Advantage (1)

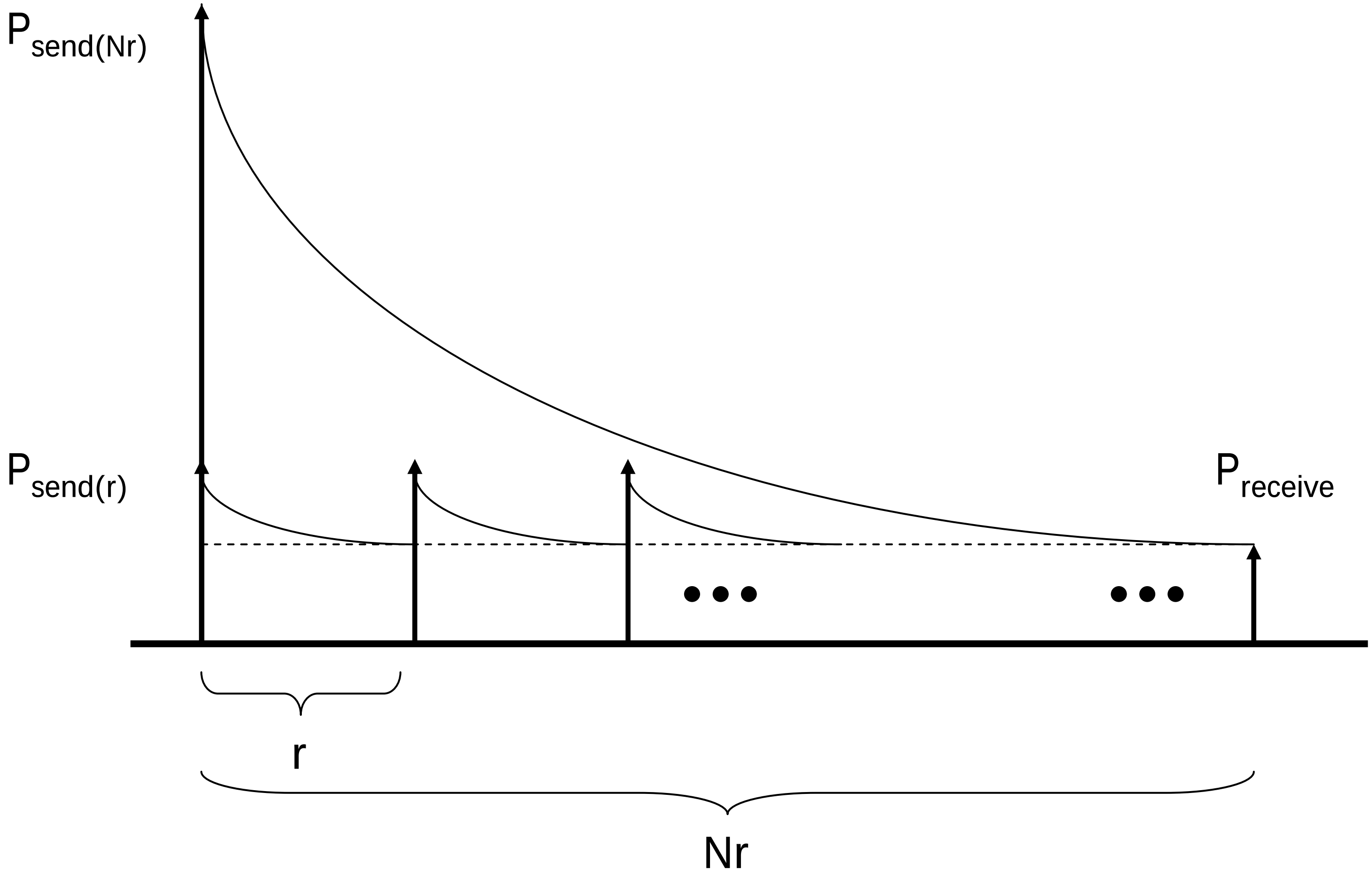
- A multihop RF network provides a significant energy saving over a single-hop network for the same distance.
  - e.g.

    $P_{send} \propto r^{\alpha} P_{receive}$
    - Due to multipath and other interference effects, α is typically in the range of 2 to 5.

Energy Advantage (2)

- The power advantage of an N-hop transmission versus a single-hop transmission over the same distance N×r is
- η_{rf}
  $=P_{send(Nr)}/N\times P_{send(r)}$
  $=(Nr)^{\alpha}P_{receive}/N\times r^{\alpha}{}_{Preceive}$
  $=N^{\alpha-1}$

Energy Advantage (3)



Detection Advantage (1)

- A denser sensor field improves the odds of detecting a single source within the range due to the improved SNR ratio.
  - e.g. (acoustic sensing)
    $P_{receive} \propto P_{source}/r^2$
    (inverse distance squared attenuation)

    $$SNR_r = 10 \log P_{receive}/P_{noise}$$
    $$= 10 \log P_{source} - 10 \log P_{noise} - 20 \log r.$$

Detection Advantage (2)

- Increasing the sensor density by a factor of k reduces the average distance to a target by a factor of 1/√k. Thus the SNR advantage of the denser sensor network is

  η_{snr}

  $=SNR_{r/\sqrt{k}}-SNR_r$

  $=20 \log r - 20 \log (r/\sqrt{k})$

  $=20 \log r/(r/\sqrt{k})$

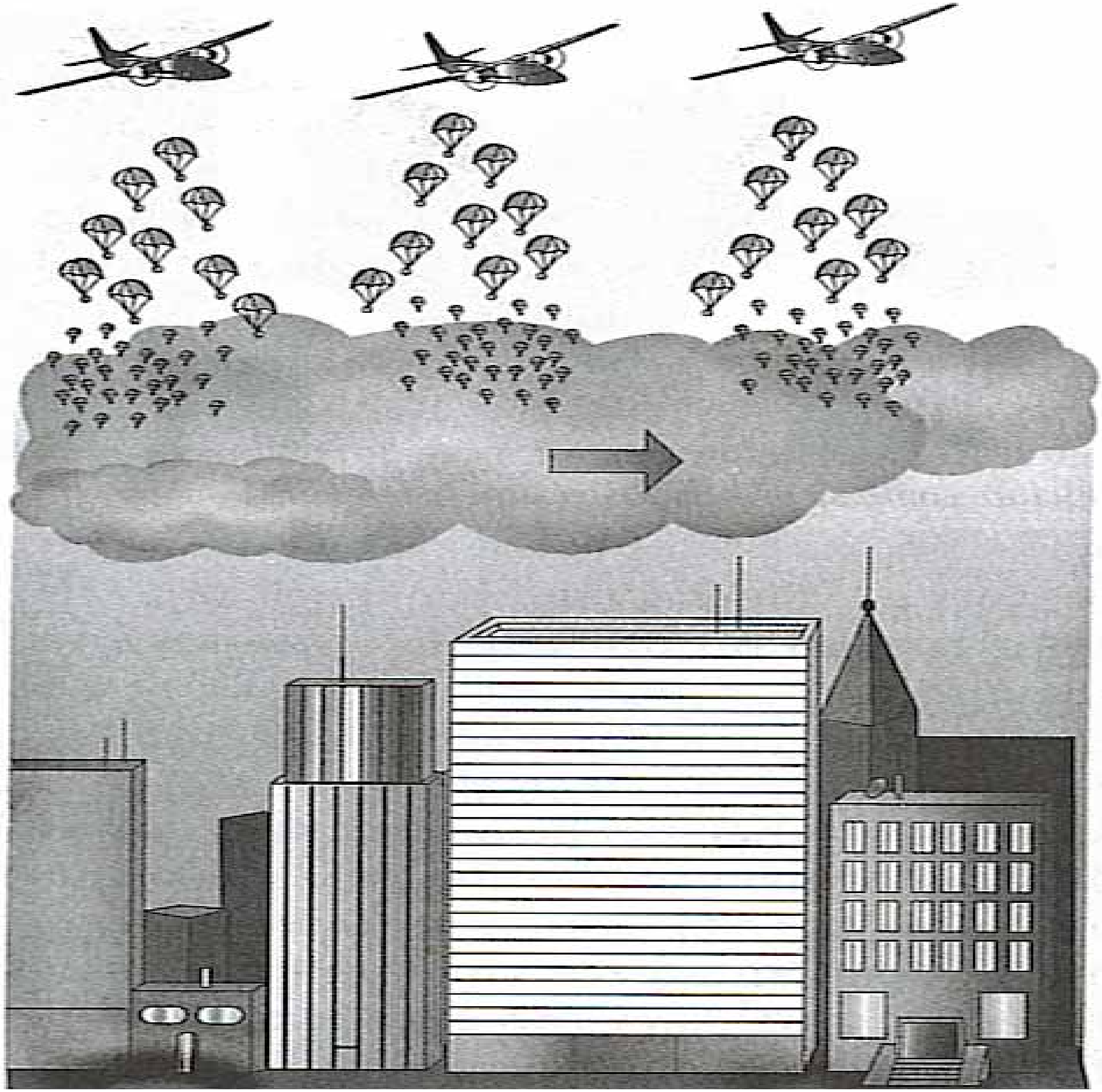
  $=20 \log \sqrt{k}$

  $=10 \log k$
- An increase in sensor density by a factor of k improves the SNR at a sensor by 10 log k db.

Applications

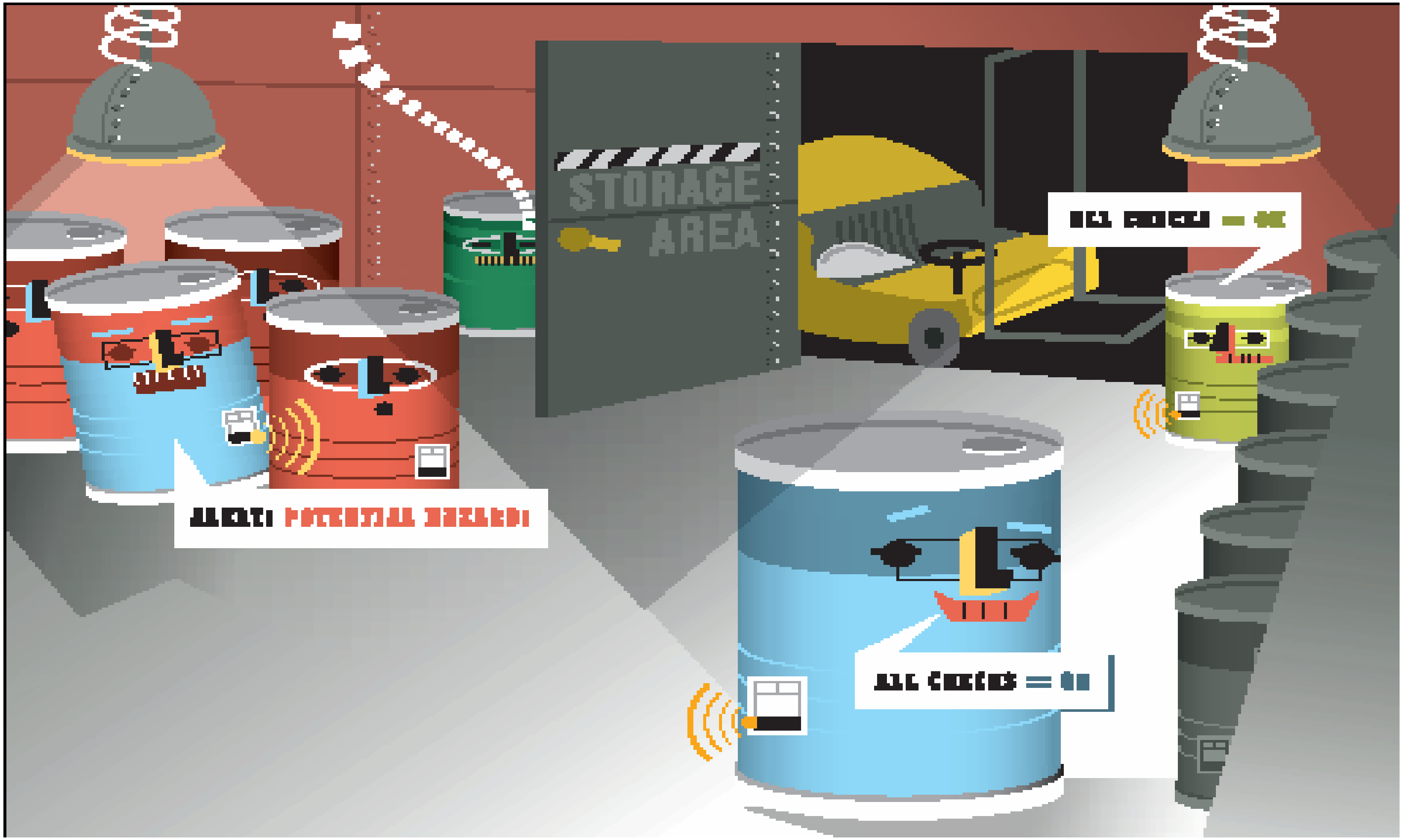
- Environmental monitoring
  - e.g., traffic, habitat, security
- Industrial sensing and diagnostics
  - e.g., appliances, factory, supply chains
- Infrastructure protection
  - e.g., power grids, water distribution
- Battlefield awareness
  - e.g., multitarget tracking
- Context-aware computing
  - e.g., intelligent home, responsive environment

Figure 3: Acrylic enclosure used for deploying the Mica mote.



Tracking chemical plumes using ad hoc wireless sensors, deployed from air vehicles.

Proactive Computing



Collaborative Processing (1)

- In traditional centralized sensing and signal processing systems, raw data collected by sensors are relayed to the edges of a network where the data is processed.
- A well-known wireless capacity result by Gupta and Kumar states that the per node throughput scales as $1/\sqrt{N}$, i.e., it goes to zero as the number of nodes increases [88].

Collaborative Processing (2)

- In a sensor network, one can remove redundant information in the data through in-network aggregation and compression local to the nodes that generate the data, before shipping it to a remote node.

Collaborative Processing (3)

- The amount of nonredundant data that a network generates grows as O(log N), assuming that the network is sampling a physical phenomenon with a prescribed accuracy requirement [206].
- This is encouraging since the amount of data generated per node scales as O(log N / N), which is within the per-node throughput constraint derived by Gupta and Kumar.
- Active control and tasking of sensors (Ch 5)

Key Definite Terms (1)

- Sensor
- Sensor node
- Network topology
- Routing
- Data-centric
- Geographic routing
- In-network
- Collaborative processing

Key Definite Terms (2)

- State
- Uncertainty
- Task
- Detection
- Classification
- Localization and tracking
- Value of information or information utility

Key Definite Terms (3)

- Resource
- Sensor tasking
- Node services
- Data storage
- Embedded OS
- System Performance goal
- Evaluation Metrics

Rest of the Book

- Ch.2 Localization & Tracking Problems
- Ch.3 MAC, Routing
- Ch.4 Time Sync., Localization
- Ch.5 Sensor Tasking & Control
- Ch.6 Database, Data-Centric Storage
- Ch.7 Platforms & Tools
- Ch.8 Applications and Future Directions