

# Mobile and Ubiquitous Computing

## Fundamental Concepts

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## Session Overview

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- The ubiquitous computing paradigm
- Elements of ubiquitous computing
- Applications and their role
- Evaluating progress in systems work
- In-depth: Implications of mobility

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## Why mobile and ubiquitous today

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- Computers camouflaged as non-computers, i.e. invisible computers
- Mobile and ubiquitous computers are orders of magnitude more than desktops and servers:
  - 8 billion embedded processors
  - 150 million desktops/servers
- Developments are coming from different disciplines:
  - built environment, embedded systems, telephony, automotive, supply chain, security, appliances etc

# Example

- BMW 745i
- 2,000,000 LOC
- Windows CE
- 53 8-bit processors
- 11 32-bit processors
- 7 16-bit processors
- Multiple networks



What networks does this car have?

What other networks can you think of?



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# Mobile Computing

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- The application of small, portable, and wireless computing and communication devices
- Being able to use a computing device even when being on the move (and thus changing location)
- Portability is one aspect of mobile computing
  - portable vs. mobile
- Mobile telephony in particular allows you to make and receive voice calls on the move

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# Mobile Computing Ingredients

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- Device
  - laptop, PDA, mobile phone, tablet, smart phone
- Network
  - cellular telephony, data over cellular, wi-fi, Bluetooth, Zigbee, infra-red, 3G, 4G
- System support
  - routing, billing, voice mail, data routing
- In-depth discussion of the issues raised by mobile systems architectures later today

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## What does ubiquitous mean?

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- Dictionary definition:
  - being or seeming to be everywhere at the same time;
  - omnipresent;
  - found in large quantities everywhere;
  - "all over the place."
- Term introduced by Mark Weiser (but others have also described the vision, notably Ken Sakamura)

# The physical/digital discontinuity

Physical



Physical (real) resources:

- People
- Objects
- Places

Digital



Digital resources:

- Object info and location
- Maps
- Person info
- Activities



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# Ubiquitous Computing

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- Ubiquitous computing:
  - activates the world,
  - is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere,
  - makes a computer so imbedded, so fitting, so natural, that we use it without even thinking about it.
- Also called: pervasive, deeply embedded, 4G mobile or sentient computing, and ambient intelligence.

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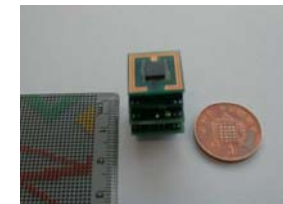
# Four Waves - Four Paradigms

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- Mainframe computing (60's-70's)
  - massive computers to execute big data processing applications
  - very few computers in the world
- Desktop computing (80's-90's)
  - one computer at every desk to help in business-related activities
  - computers connected in intranets to a massive global network (internet), all wired
- Mobile computing (90's-00's)
  - a few devices for every person, small enough to carry around
  - devices connected to cellular networks or WLANs
- Ubiquitous computing (now)
  - tens/hundreds of computing devices in every room/person, becoming “invisible” and part of the environment
  - WANs, LANs, PANs – networking in small spaces

# Enabling Technologies, Part 1

- **Wireless (data) communication**
  - higher bandwidth
  - lower power
  - commodity (readily available and secure)
- **Small form factor devices**
  - shrinking electronics
  - better displays
  - new input methods
- **Personalisation**
  - Machine learning
  - Inference



# Enabling Technologies, Part 2

- Automatic identification
  - RFID, numbering schemes, network information services
- Sensing and actuation
  - mechanical, chemical, electric, bio
- Context awareness
  - physical: properties of objects
  - Information: data, profile, provider
  - social: identity, situation, role
- Ambient displays
  - public screens, interaction
- Tangible interfaces



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# Extremely Varied

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- Embedding for smart control
  - Embedded systems for cars, airplanes, etc.
- Creating new computing devices
  - Hi-tech, silicon-based gadgetry, e.g. PDAs, cell phones, mp3 players, active displays
- Connecting the existing physical world to a computational infrastructure
  - Ordinary objects and tasks re-evaluated and extended with computational/communication capabilities

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# Applications First

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- How can we enhance [everyday] activities by connecting them to a computational infrastructure?
- What computational infrastructure do we need?
- Applications are a good way to explore a new paradigm before we have a complete specification of the problems/open questions

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# Computer Science and Engineering Issues

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- Interaction design
- Security + Privacy + Trust
- Communications and networks
- Operating systems
- Hardware design
- Software design
  
- The whole field! (and more: social science essential)

# Interaction Design

- The interface
  - Very small interface
  - Tangible interface
  - No interface
  - Everywhere interface
- Overcoming real-estate shortage
  - new devices, voice / video input (e.g gestures)
  - intelligence
- How to address many systems rather than computers (without going insane)
- Context-awareness





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# Trust

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- wireless systems
  - pervasive access points to network
  - implementing surveillance
  - overcoming surveillance
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- control
  - trust vs. trustworthiness

# Communications & Networking

- home networks, personal area networks, ad-hoc networks, consumer electronics networks, building networks, public access networks
- new media (e.g. sound, chemicals, bio-sensing, feelings)
- new ways of using existing media
- new metrics: bits/s/m<sup>3</sup>
- How to leverage all the available networks to provide **global** services (scope, scalability, standardization)



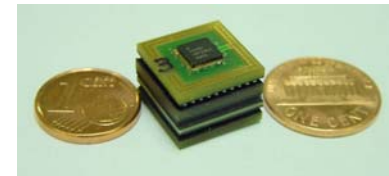
# Operating Systems & Middleware

- Resources
  - Limited resources
  - Power-aware, heat dissipation
  - Resource management
- Generic vs. specialized
- Dependable (complexity, validation, verification)
- Mobile (time, performance, location, disconnection)
- Real-time DSP



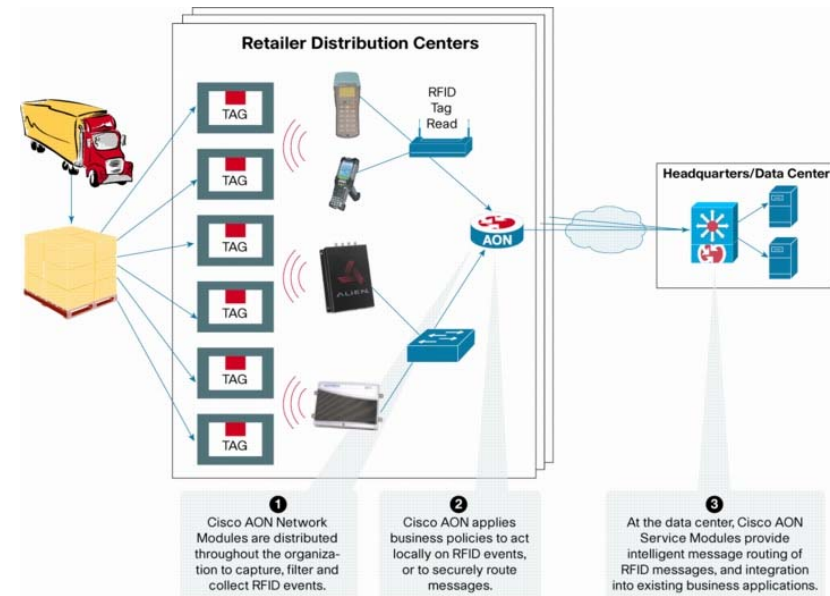
# Hardware Design

- Small size, low weight, low power
- May have to be deployed in harsh environments
- Production: extreme cost sensitivity
- Fast product cycles
- New sensing capabilities



# Software Design

- Must cope with large variation in hardware
- Must cope with rapidly changing requirements
- Programming the system, rather than the devices
- How to partition the code so that it can be easily customized in different environments



CISCO Application  
Oriented Networking

- New, hierarchical, multi-context architectures

# Auto-Identification

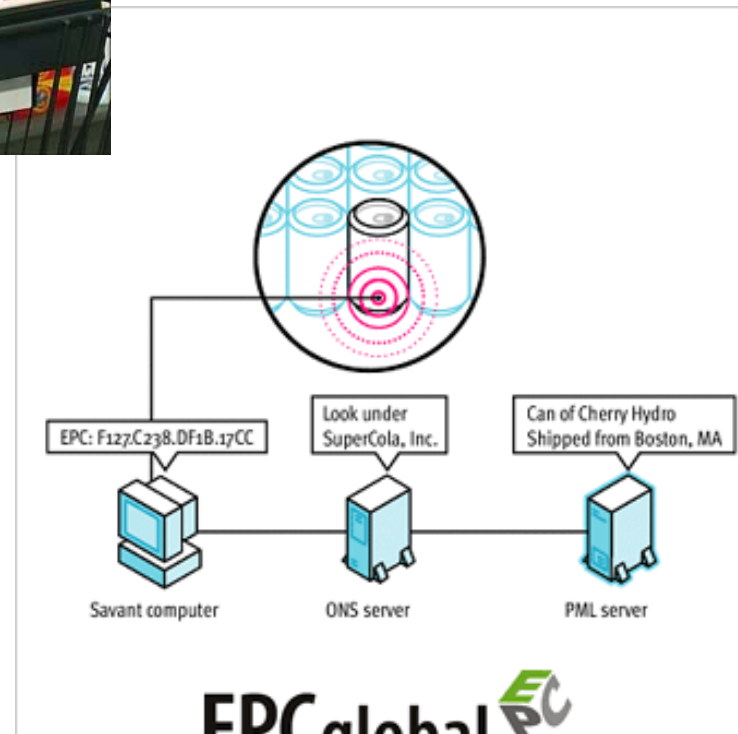


Middleware for improved RFID reading accuracy

Caching strategies for ONS performance

Location tracking using WLAN and RFID data

Systems architecture for ERP integration



EPCglobal

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# Context-Awareness

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- The physical environment: user location, presence of other persons or objects in the same location, and the environmental conditions observed.
- Time — for example, whether a particular person is occupied by professional or personal concerns.
- Device and network characteristics
- Information context is the semantic knowledge regarding the domain being investigated—for example, the short-term information needs of the user as they might be expressed in a query. Information context also includes the user profiles that reveal long-term interests
- Social context

# Applications 1

## Active Theatre *Aarhus University*



- The project focuses on novel ways of using computers before, during and after surgery
- Ambient displays are used to support collaborative work

<http://www.pervasive-interaction.org/ActiveTheatre/>



## Applications 2

### Aware Home

*Georgia Tech*

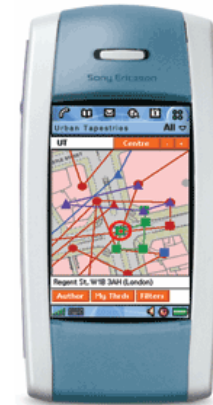


- Addresses challenges facing the future of domestic technologies
- The Gesture Pendant allows ordinary household devices to be controlled with the wave of a hand

<http://www.awarehome.gatech.edu/>

## Applications 3

### Urban Tapestries *Proboscis*



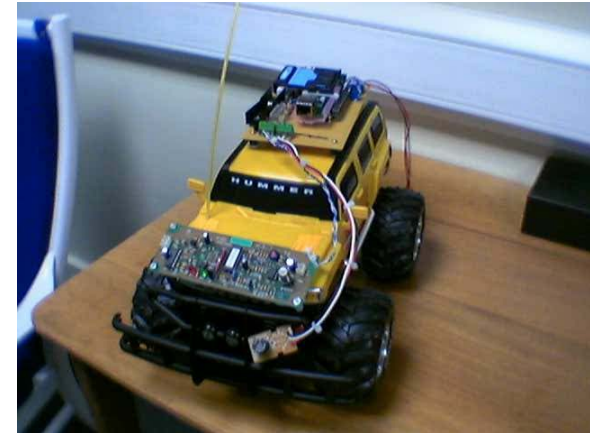
- An experimental software platform for knowledge mapping and sharing ie. public authoring
- It combines mobile and internet technologies with geographic information systems to allow people to build relationships between places and to associate stories, information, pictures, sounds and videos with them

<http://urbantapestries.net/>

## Applications 4

### Feral Robots v2

*Birkbeck and Proboscis*

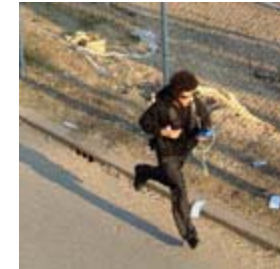


To design and create practical applications from commercially available technologies for social and cultural public benefit such as adapting a remote control toy car into a powerful sensing device for locating and identifying chemical pollution and radiation

<http://socialtapestries.net/feralrobots/>

## Applications 5

### Uncle Roy All Around You *Equator*



Street Players use handheld computers to search for Uncle Roy, using the map and incoming messages to move through the city. Online Players cruise through a virtual map of the same area, searching for Street Players to help them find a secret destination.

<http://www.uncleroyallaroundyou.co.uk/>

## Applications 6

### Great Duck Island Project

*UC Berkeley*



Very large wireless sensor network deployment on Great Duck Island, Maine, aiming to monitor the microclimates in and around nesting burrows used by the Leach's Storm Petrel

<http://www.greatduckisland.net/>

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# Mobile Computing in More Depth

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- Wireless communication
  - Disconnection
  - Low bandwidth
  - High bandwidth variability
  - Heterogeneous networks
  - Security
- Mobility
  - Addressing and routing
  - Location based information
  - Migration
- Portability
  - Low power
  - Small interface
  - Restricted storage
  - Security

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# Wireless Characteristics

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- Wireless is primary network interface, may attach via cable on and off
- Implication: signal interacts with the environment
  - noise, echoes (multi-path, timing), blocking
  - objects, walls, other sources, weather
- Implication: network topology very dynamic
  - hosts come and go, loss of connectivity, variable density
- Result: degradation/variability of capability to communicate, errors
- Networks and applications must deal with this

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# Communications Challenges 1

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- Disconnection
  - autonomy of operation vs. centralized operation
  - delay tolerance: asynchronous operation, pre-fetching, lazy write-back, caching
  - execution quality guarantees
- Low bandwidth
  - cellular 9-14 kbits, GPRS 171 kbits (theory), 40-60 kbits (real), infrared 1Mbits, Bluetooth 1-10 Mbits, Wi-Fi 2-57 Mbits
  - shared between users!
  - limited transmission range!



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## Communications Challenges 2

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- High bandwidth variability
  - adaptation
  - move from area with GPRS to simple cellular
- Heterogeneous networks
  - different (physical) interfaces
  - different network structure (e.g. cellular vs. ad-hoc)
- Security
  - eavesdropping on the air
  - easy to move between security domains
  - may have limited access to resources (e.g. software updates)

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# Mobility: Addressing and Routing

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- Moving from access point to access point
  - How do you handle the change
  - How do you reroute data to the new location
  - Who is responsible for maintaining correct operation
- These actions are mostly taken by persons on wired networks
- One solution: Mobile IP
- Will discuss in details

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# Mobility: Location Based Computing

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- How to take into account the location of the host and the user
  - to access resources nearest to you
    - more relevant, better performance
    - local restaurant, closer data servers
  - to modify the operation of software e.g. discover new services available locally
- Technology: many different depending on
  - wireless system used, indoor-outdoor, type of location needed
  - GPS, location tags, vision, triangulation etc
- A whole session will be on this!

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# Mobility: Migration

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- Device
  - start work on a PDA and continue on a phone
  - processes, data, state
- Location
  - start work on the train and continue at home
  - security, resources, preferred attachment
- Context
  - use the same resource to work and then to entertain
  - cost, security, resources, identity

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## Low power

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- Mobile power source = battery
- Reduce processor and network power consumption
  - on/off cycles
  - reduce frequency
- Adaptation
- New: data harvesting
  - solar power, vibration, thermal power

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# Small Interface

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- Small display/screen size
  - need for interaction alternatives
  - need for summarization
- Restricted input device
  - no mouse, no full keyboard
  - keypad or less, voice recognition
- External devices
  - Bluetooth headphones, printers, interaction with external displays

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# Restricted Storage

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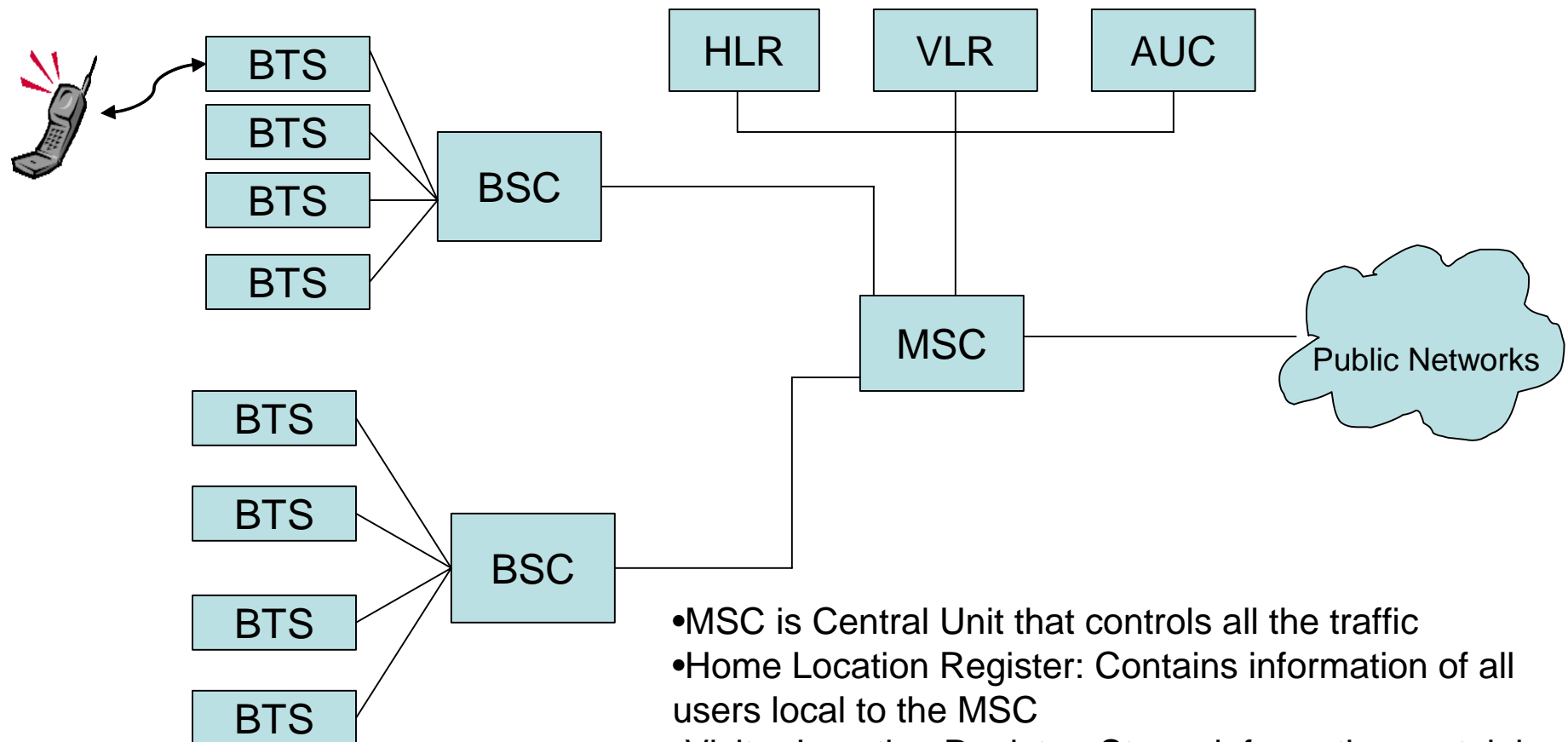
# Security

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- “The protection of information systems against unauthorized access to or modification of information, whether in storage, processing or transit, and against the denial of service to authorized users or the provision of service to unauthorized users, including those measures necessary to detect, document, and counter such threats” US INFOSEC
- Integrity, confidentiality, availability, non-repudiation
- Hostile environment
- One session dedicated to this



# Cellular System Architecture



- MSC is Central Unit that controls all the traffic
- Home Location Register: Contains information of all users local to the MSC
- Visitor Location Register: Stores information pertaining to roaming Mobile Station currently in this MSC
- Authentication Center: Stores all the encryption keys

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# Experimental Systems Research

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- The scientific method
  - hypothesis, **experiment**, **validation** and replication
- How to formulate a hypothesis
  - What is the basis for your hypothesis?
  - What are the implications of your hypothesis?
- What is the expected result
- Design experiment to show the causal effect
- Ensure correctness and replication

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# Summary

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- The ubiquitous computing paradigm
  - Challenges
  - Novelty
- Elements of ubiquitous computing
  - Technology and science
- Applications and their role
- Conducting experimental systems research