Opportunities in Opportunistic Computing

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Organization

- Background and Motivation
- Distinctions
- Opportunistic Computing
- Contacts, Paths
- Issues and challenges
  - ***Can we do distributed computing in an opportunistic networking environment?***
- Applications

Opportunistic contact

Capacity of the contact

- Time duration of the contact
- Available bandwidth

Frequency of contacts

Two devices are within communication range

Security and privacy

- Trust between the two devices/users
- Secure communication channel

Resources on each device

What is opportunistic computing?

More than exchange of packets/bundles

- *Content distribution and information management*
- *Remote task execution*
- *Cyber foraging*
- *Resource sharing*
- *Service composition*
- *Trust and authentication*
- ***Enabling pervasive applications***
- ***Anywhere, anyhow, but later***

Background

Wireless ad hoc networking

- *Novel algorithms and schemes developed*
- *Cooperation in the absence of infrastructure*

Pervasive computing

- *Context-aware services to users/applications*
- *Smart environments*

Distributed resources

- *Mobile devices possess myriad of resources*

Opportunistic communications

- *Exchange of packets/bundles*

Social networks and computing

- *Exploit gregarious nature of humans*

Computing Paradigms

Computing – 1940s …

- *Uniprocessor architectures, limited applications*

Parallel Computing - 1970s …

- *Multiprocessor systems, computationally intensive tasks*

Distributed Computing – 1980s …

- *Collaboration in networked systems, Resource Sharing, Business applications, the Internet, WWW*

Mobile Computing – Mid 90s …

- *Anytime anywhere computing*

Grid Computing – 90s …

- *Effective utilization of resources*

Pervasive Computing – 00s …

- *User centric, quality of life,*

Opportunistic Computing – Mid 00s …

- *Adapting to users' social behavior, …*

Fading Distinctions

Servers and clients

- *Distributed systems, P2P systems*
- *Cost and time*

Producers and consumers of information

- *Users are producers of information as well*
  - User with a cell phone camera

Service providers and consumers

- *Resources on user devices can be exploited*

Resourceful and resource-poor entities

- *Servers, desktops, laptops, mobile phones*
- *Grid computing*
- *Cyber foraging*

Window of Opportunity

Time is ripe

- *Mobile ad hoc networks*
- *Wireless communication technologies*
- *Pervasive computing and smart environments*
- *Sensor systems*
- *User mobility and social behavior*
- *Distributed resources*

Need for Opportunistic Computing

Opportunistic connections and paths exist

Resources are distributed in challenged and highly dynamic environments

Cost effective

- *Communicate, distribute when needed*

User generated information/events

- *Anywhere, anytime*
- *Large*
- *Frequent*

Automatic filtering

- *Limited buffer space*
- *Purge unwanted data*

User-centric applications

- *Expensive for users to adapt their mobility*
- *Limited user attention*

Opportunistic computing can be Green

- *Servers, routers, communication channels are not used*
  - **Selective Networking**
  - **Energy savings**

Delay/disruption tolerant applications

Soft-real time applications

- *Vehicle-to-vehicle data dissemination*
- *Traffic monitoring*
- *Collaboration among robots*

Sender-receiver disconnection tolerant

- *Document transfers*
- *Remote task execution*

Non-critical monitoring applications

- *Tagging animals*
- *Dissemination of events*

Email, FTP, message passing

MANETs Vs. Opportunistic Networks

Message forwarding in MANETs

- *High density and high mobility of nodes*
  - Maintenance of end-to-end paths
    - *Knowledge acquisition is expensive*
- *Energy consumption is high*
- *Low density and low mobility*
  - Low reachability
  - Low reliability
  - High congestion due to bottlenecks

In ONs

- *Delayed*
- *Opportunistic*
- *Possibly low cost*

Delay/Disruption Tolerant Networks

Terms used interchangeably

In ONs

- *Each node acts as a gateway*

What are DTNs?

Delayed tolerant networks

- *Tolerate delays*
- *Store and forward principle*
- *Persistent storage at (DTN) network routers/gateways*

Characterized by

- *Long delay paths*
- *Frequent network partitions*
- *Intermittent connectivity*
- *Asymmetric data rates*
- *Varying message propagation rates*
- *Need for buffers*
- *No end-to-end connectivity*

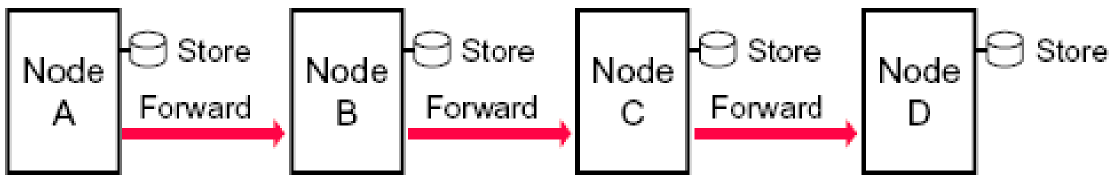
V. Cerf et. al., "Delay Tolerant Network Architecture", draft-irtf-dtnrg-arch-05.txt, September 2006
K. Fall, " A Delay-Tolerant Network Architecture for Challenged Internets", IRB-TR-03-003, Feb., 2003
F.Warthman, "DTN Tutorial", May 2003

Examples

- DakNet project [Pen04] uses busses equipped with an access point to collect and deliver data packets from/to villages on a route.
- Wizzy project [Wiz] uses digital couriers to disseminate info (from the www) to rural schools.
- In [Sma03], the authors describe a project where whales are tagged with a sensor that records positional information.
- ZebraNet project [Jua02] track zebras using a similar concept, but collects recorded data using a jeep.
  - *oceanographers tag seals to obtain a better reading of ocean temperature.*

[Pen04] A. Pentland and R. Fletcher (2004), **DakNet: Rethinking Connectivity in Developing Nations**, IEEE Computer, 37(1), pg 78-88, January, 2004.
[Wiz] Wizzy Project. http://www.wizzy.org.za/
[Sma03] T. Small and Z. Haas (2003) **The Shared Wireless Infostation Model – A new Ad-Hoc Networking Paradigm (or Where there is a Whale, there is a Way)**, ACM MobiHOC'03, Annapolis, Maryland, June 1-3, 2003.
[Jua02] P. Juang, H. Oki, Y. Tong, M. Martonosi, L-S. Peh and D. Rubenstein (2002) **Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet**, ACM ASPLOS'02, San Jose, CA, USA.

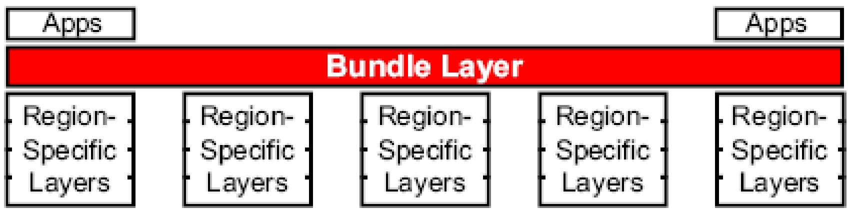
DTN Architecture

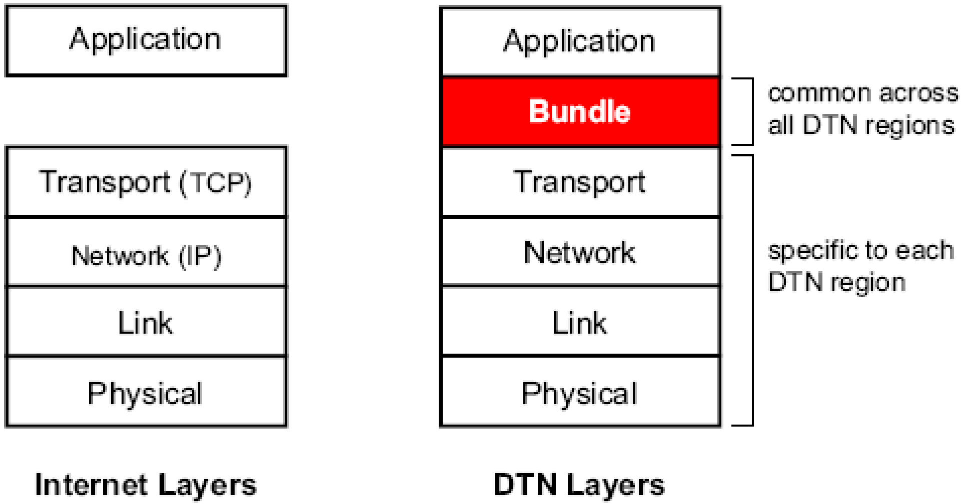


- Overlay network above the transport layer
- Aggregate of message called a bundle used to transfer data from one node to next
- Routers that handle bundles are called “bundle forwarders” or DTN gateways
- DTN forwarders store and forward data moving it from source to destination

DTN Architecture

- A new protocol layer called bundle layer is overlaid on region-specific lower layers
- Applications can communicate across different regions using the bundle layer
- Single bundle-layer protocol is used across all networks of DTN





Distributed Computing

Heterogeneity
- *CORBA,RMI, Mobile code*

Resource sharing
- *Wide and well developed*

Security
- *Partial*

Scalability
- *The Internet*

Failure handling
- *Partial success*

Concurrency
- *Grid computing, well developed*

Transparency
- *Minimal user effort*

Openness
- *Modular, portable software*

M. Colouris et al, Distributed Computing: Conecpts and Design, 4^{th} Edition 2005, Addison Wesley,

Pervasive Computing

Proactivity and transparency

- ***Delays, resource utilization, unobtrusive services***

Heterogeneity and interoperability

- ***Unevenness, incompatibility, h/w, s/w, communication channel***

Location awareness and mobility

- ***Handoff- vertical/horizontal, data dissemination/acquisition***

Authentication and security

- ***Privacy vs. services, cost, agents, active networks, availability***

Smart environments

- ***Deployment, Interference***

Opportunistic Computing

Tolerate intermittent connections and delays

Mask unevenness, Conserve energy, Manage information

M. Satyanarayanan, “Pervasive Computing: Vision and Challenges,” IEEE Personal Computing, August 2001.

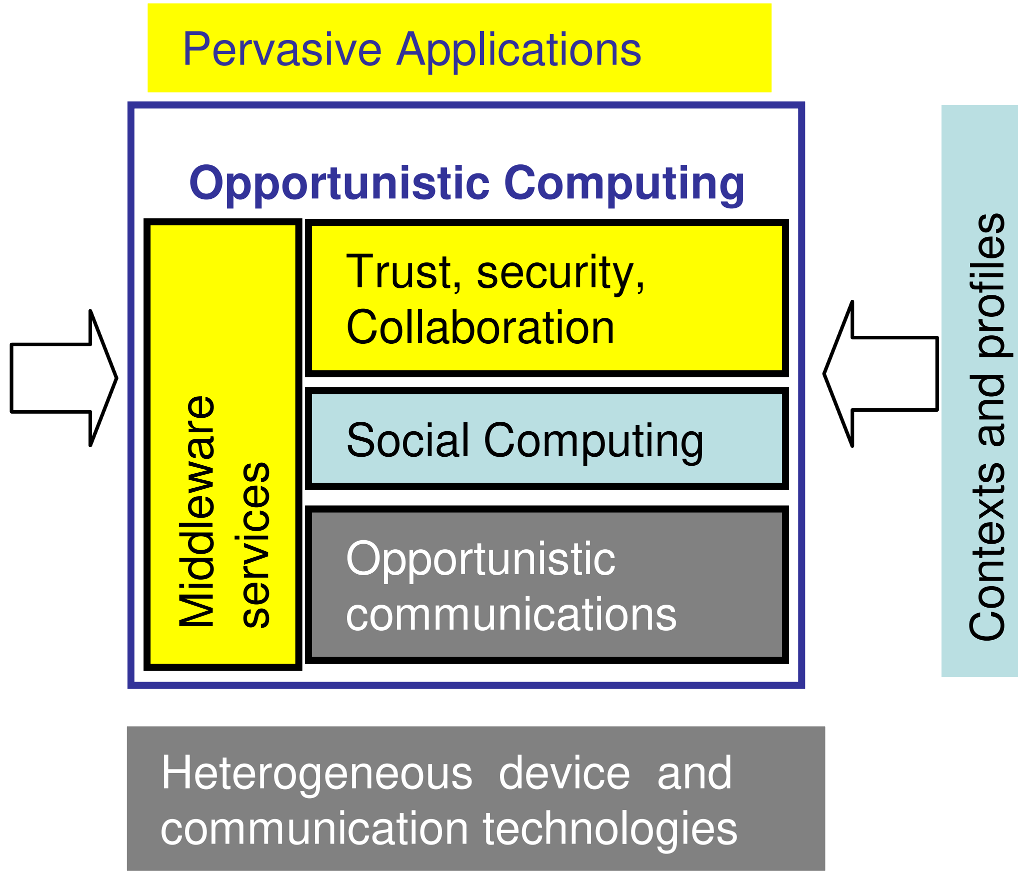
Opportunistic Computing

Sensor systems
Pervasive computing

Distributed and Fault-tolerant Computing

Mobile and Ad hoc networking

Algorithms, protocols and schemes



Opportunistic contacts

Cell phones

- *4 Billion users worldwide*
  - Internet Population – 1.3 Billion (2008)
- *Global annual growth – 22%*
- *One in three persons carry a cell phone*
  - More than 1 billion opportunistic contacts at any given time
    - *Not counting sensors and RFID Tags*

10 billion ARM processors

- *In cell phones and other mobile devices*

Millions of vehicles on the road

- *Many equipped with cameras, computing devices, GPS systems*

In a typical downtown (CBD) area

- *O(100) street cameras*
- *O(1000) user cameras*
- *O(1000) user devices, laptops, PDAs*
- *O(100) desktops, infoservers*

http://www.cnet.com; http://infoplease.com; http://arm.com/products

Potential

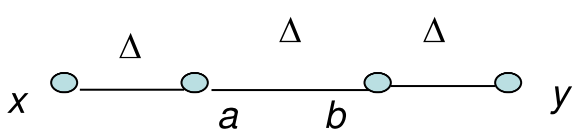
One Terra opportunistic contacts

- *Each processor*
  - 100 MIPS
  - 1K distributed tasks per second
- *Each contact*
  - 200 kb/s (conservative)
  - 5 seconds
- *At any time instant*
  - 1 Peta distributed tasks
  - 1 Peta bytes of data exchange

Challenges

- Low mobility and low density areas
- Low contact times
- Noisy channels
- Hard-real time applications
- Trust and security
- Information overload
  - *Aggressive routing*
  - *Redundant information*

Opportunistic path



Cooperation and collaboration

Comprises multiple opportunistic contacts

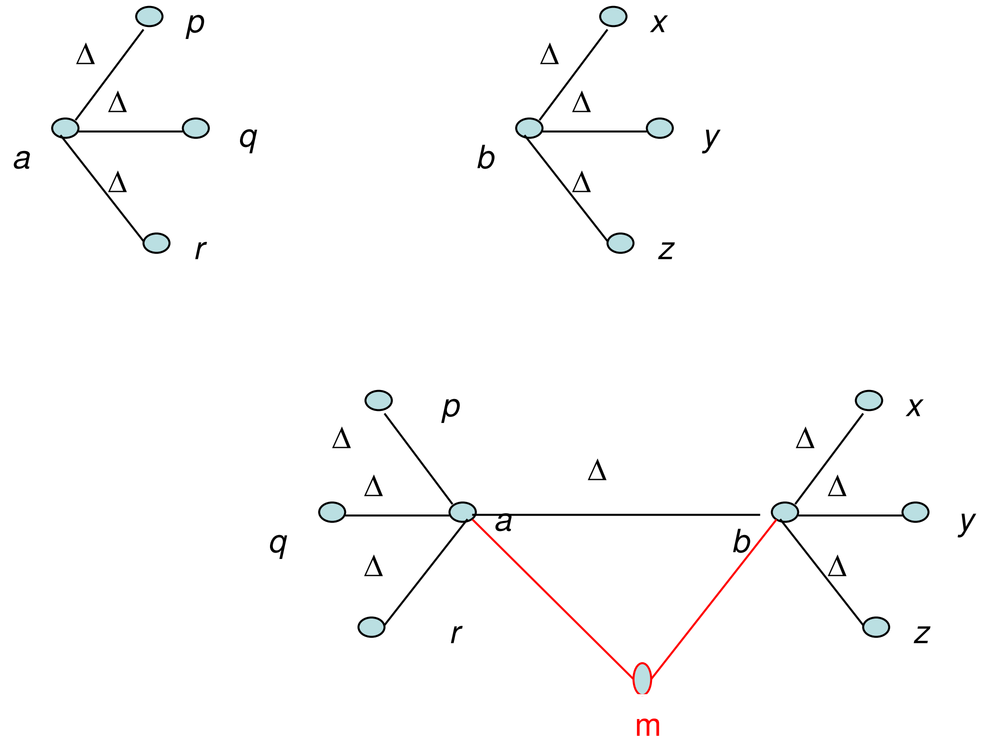
Path delay

- *number of contacts*
- *Δ is the expected delay for each contact*

Intermediate nodes

- *Store and forward*
- *Possess adequate buffer space*

Opportunistic paths



Challenge: Establishing reliable path for cooperation and collaboration

Routing and Forwarding

Dissemination-based and context-based

- *Dissemination*
  - Message is forwarded everywhere
  - Resource intensive
    - *Epidemic routing [Vahdat00]*
    - *Controlled probabilistic routing [Oikonomou07]*
    - *PROPHET Coding[Lindgren03]*
    - *Network Coding[Widmer05]*
- *Context*
  - Identify next hop based on context
    - *Context-aware routing[Musolesi05]*
    - *Mobyspace routing[Leguay06]*
    - *HiBOp[Boldrini07]*

Challenge: Manage information efficiently

Controlled dissemination – what you want, where you want

Social networking

Social behavior

- *Mobility models*
- *Routing Schemes*
- *Forwarding decisions*

Social structures

- *Cooperate and communicate*
- *Smart pervasive environments*

Socialnets vision

- *Understand*
  - Human relationship/connectivity
- *Model*
- *Exploit*

Challenge:

- Use social models to aid
- Efficient information management, trust and collaboration

Social networking

Inter-group

- *hierarchical*
  - The message packets move from group to group, rather than node to node
    - *Hierarchical data movement*
    - ***Worst case – Logarithmic***

Intra-group

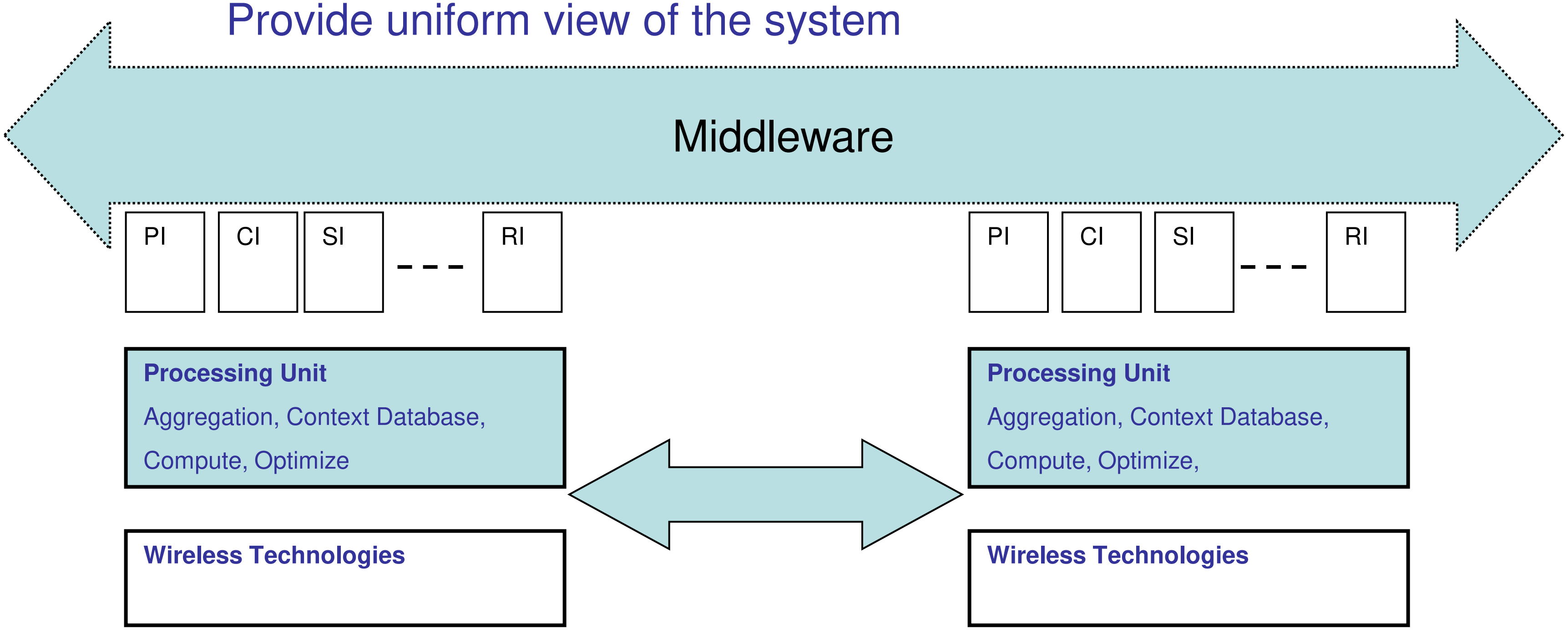
- *Constant number of hops*

Delayed

Middleware

Mask disconnections, delays

Provide uniform view of the system



Legend: PI- ID, basic user and device information, CI- Content Index, SI – Service Index, RI – Reputation Index

Middleware services

- Route packets
- Perform services
- Disseminate/acquire and find information
- Identify malicious nodes
- Find fastest path
- Find multiple paths
- Respond to queries

Challenge:
Trust?
Quaility?
Reliable?

Content distribution and management

Lack of distinction between producers, consumers, and forwarders

Content generated anywhere anytime

- *Share, transmit*
- *Time to live and Hops to live limits*
- *Security, privacy and trust*

Limited buffer/cache space

- *How to acquire? What to store? Where to store? What to purge?*

Effective cache management strategies

- *Social group based*
- *Application based*
- *Consistency*

Query processing and management

- *Multiple queries*
- *Scalability*
- *Spatial and temporal consistency*

Information Caching

Store and forward data

- *Default*
- *Temporary data*
- *What to purge? and what to store?*

Acquisition

- *In house applications*
- *Social group applications*
- *Priorities*

Dissemination

- *Generated within node or social group*

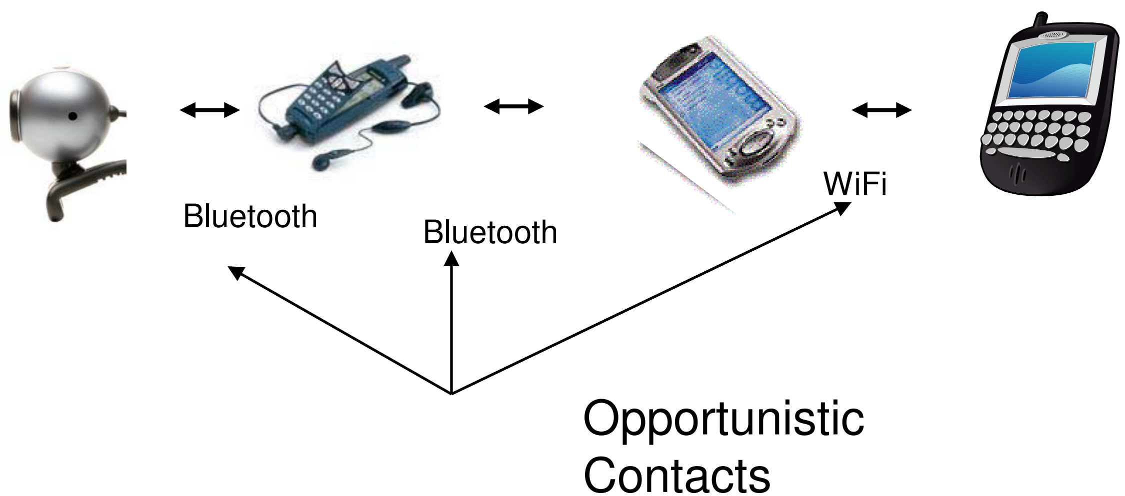
Caching

- *Optimal management of limited cache space*
- *Data consistency*
- *Local cache and group cache*

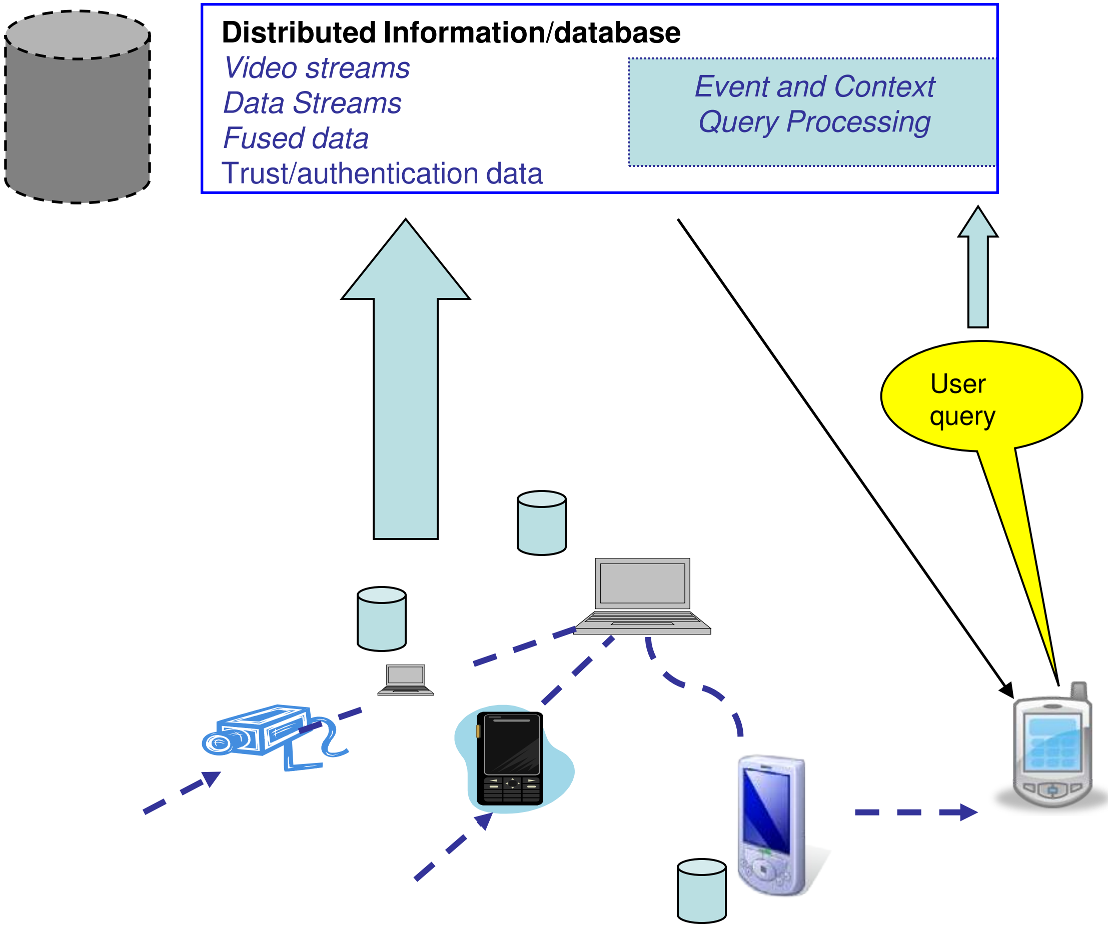
Resource sharing

Application on PDA needs a video stream from camera

- *No direct link to camera*
- *Use cell phone as a forwarder*
  - Bluetooth connection between camera and cell phone
- *iPaQ PDA receives video stream and transmits processed stream to Blackberry*
  - Check authentication, process video stream



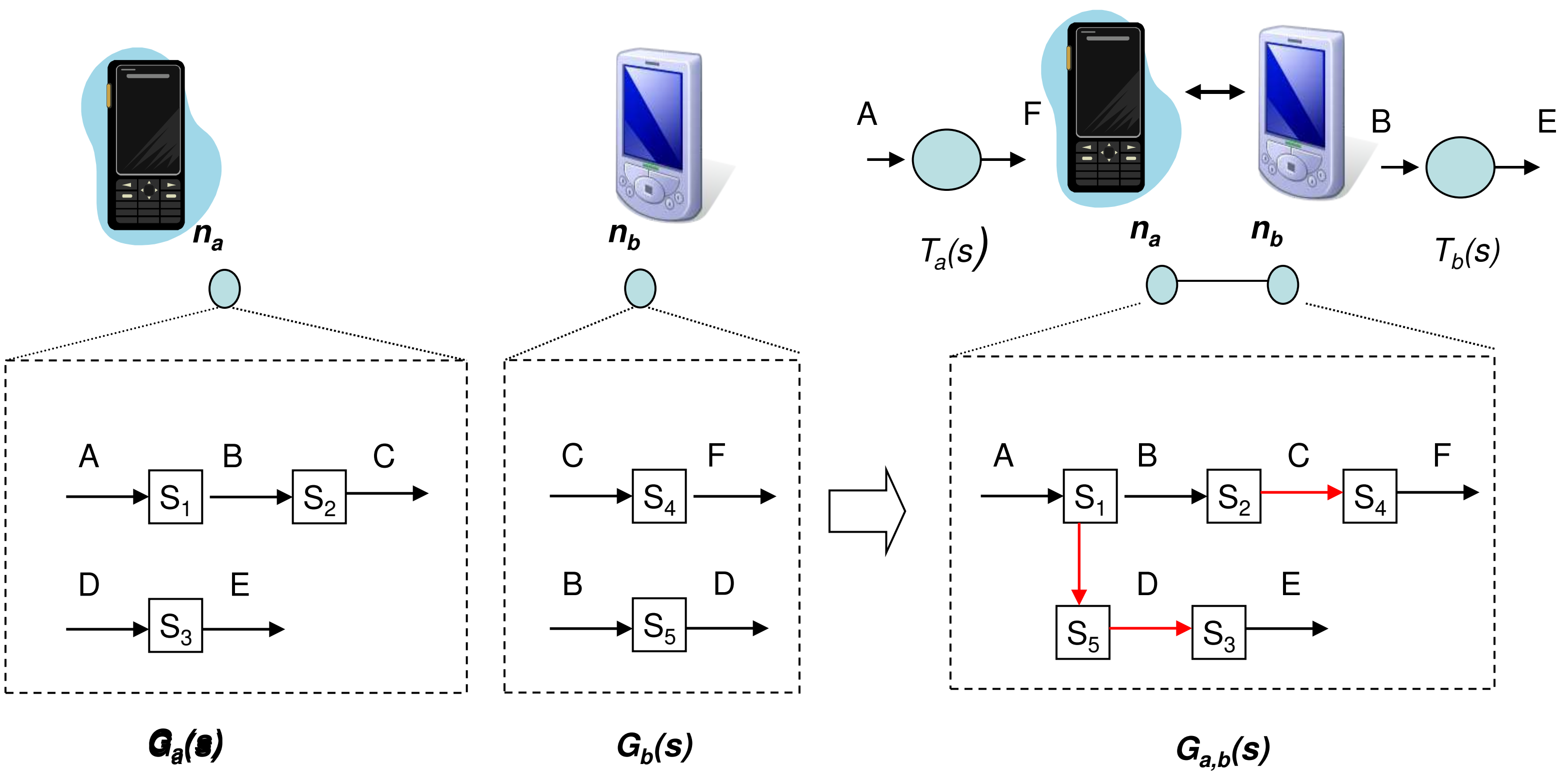
Query processing



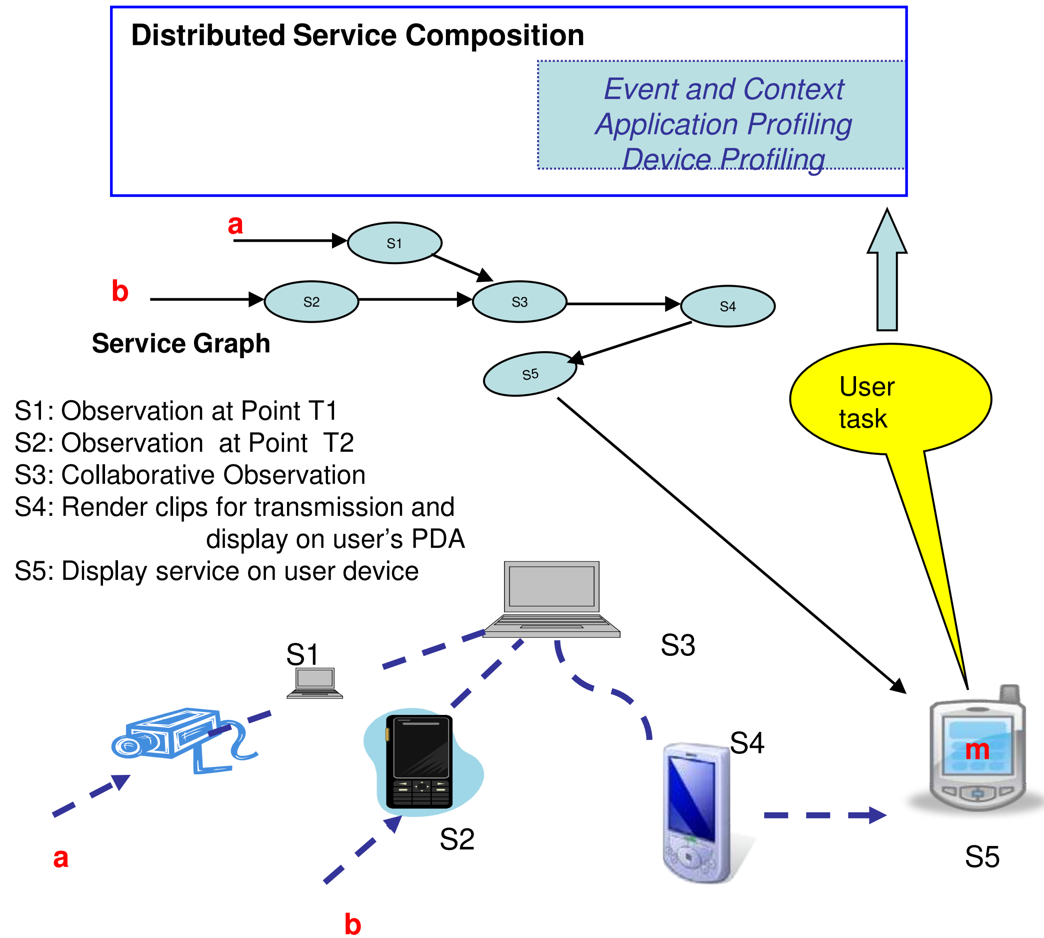
Challenge:

User mobility and anonymity

Services and composition



Service Composition - Example



Challenge:
Maintain incomplete and dynamically changing graphs

Trust, security and cooperation

Traditional schemes

- *Online trusted authorities*
- *Certificate repositories*
- *Eigen Trust*
  - Distributed tables

In social networks

- *Notion of trust fundamentally embedded in the environment*
- *Humanistic orientation to establish trust*
- *Social groups*

New models for trust

- *Social dynamics*
- *New definition for reputation*
  - Availability
  - Next contact

Mobile nodes as Data ferries

In situations where nodes are static

Provide *contacts* for information exchange and service provisioning

Data mules [?]

- *Helicopters fetch data from sensors*

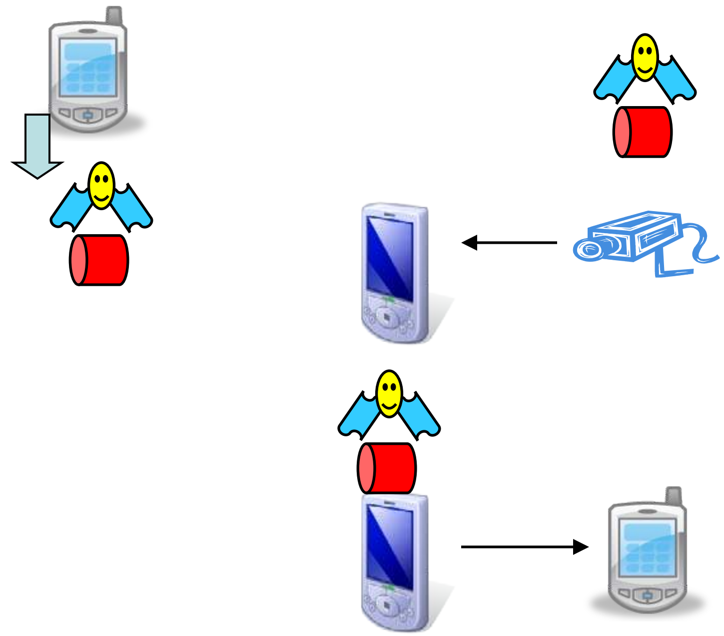
Virtual observation of points of interest [Greenhill06,07]

Mobile Agents

Migrate from one node to another during contact

- *Carry input data and code*
- *Exploit resources at all visiting nodes*

Perform tasks and return with results



Challenge:
Security, latency

Mutual Exclusion

- Multiple nodes in a network need exclusive access to share resource.
- Critical section
- Properties:
  - Safety: At most one node must be executing its critical section at any given time
  - Liveness:
    - Freedom from starvation
    - Freedom from deadlock
  - Ordering

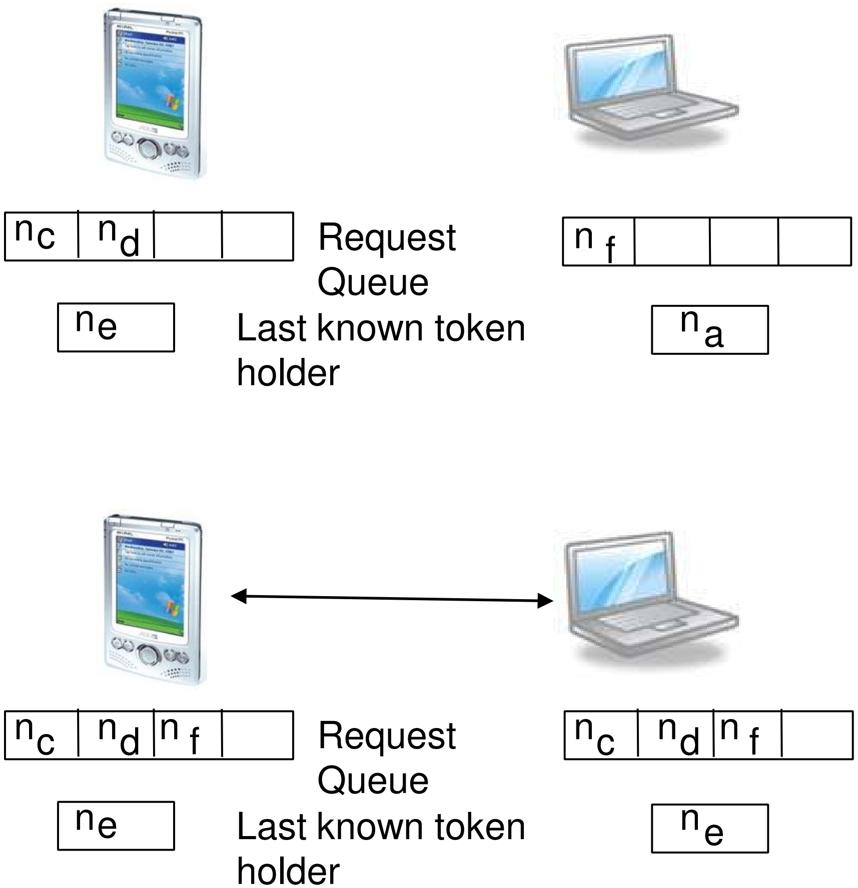
39

Proposed Algorithm

Mutual Exclusion for Opportunistic networks (MEOP)

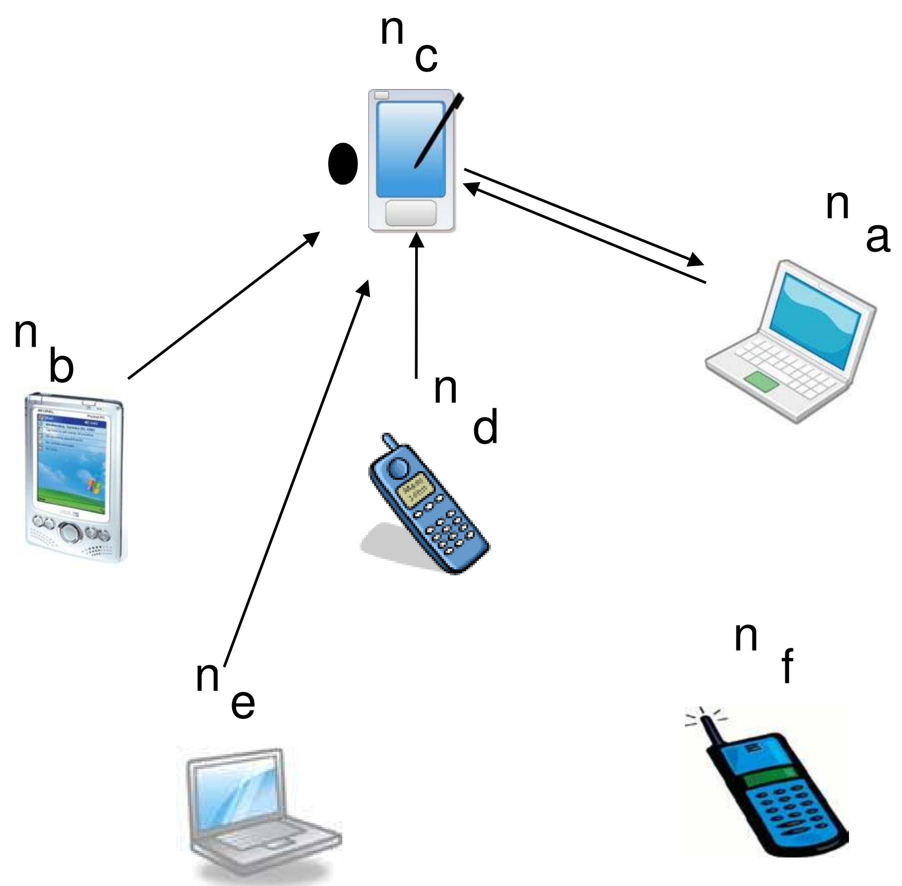
- DAG based
- Reduced communication overhead
- Independent of routing algorithms
- Fault tolerant

MEOP

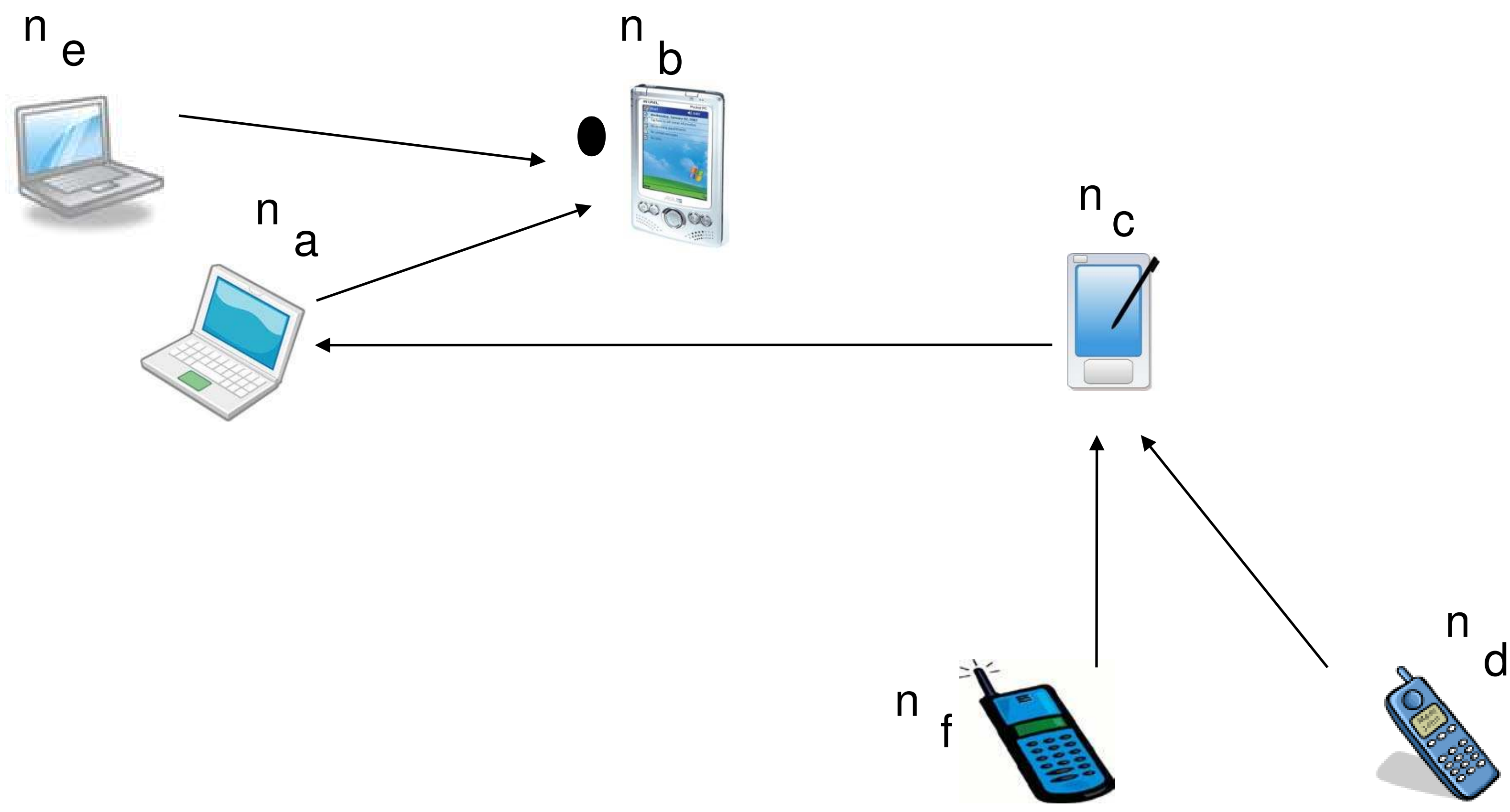


- Request Generation
- Request Propagation
- Token Propagation
- Fault Tolerance

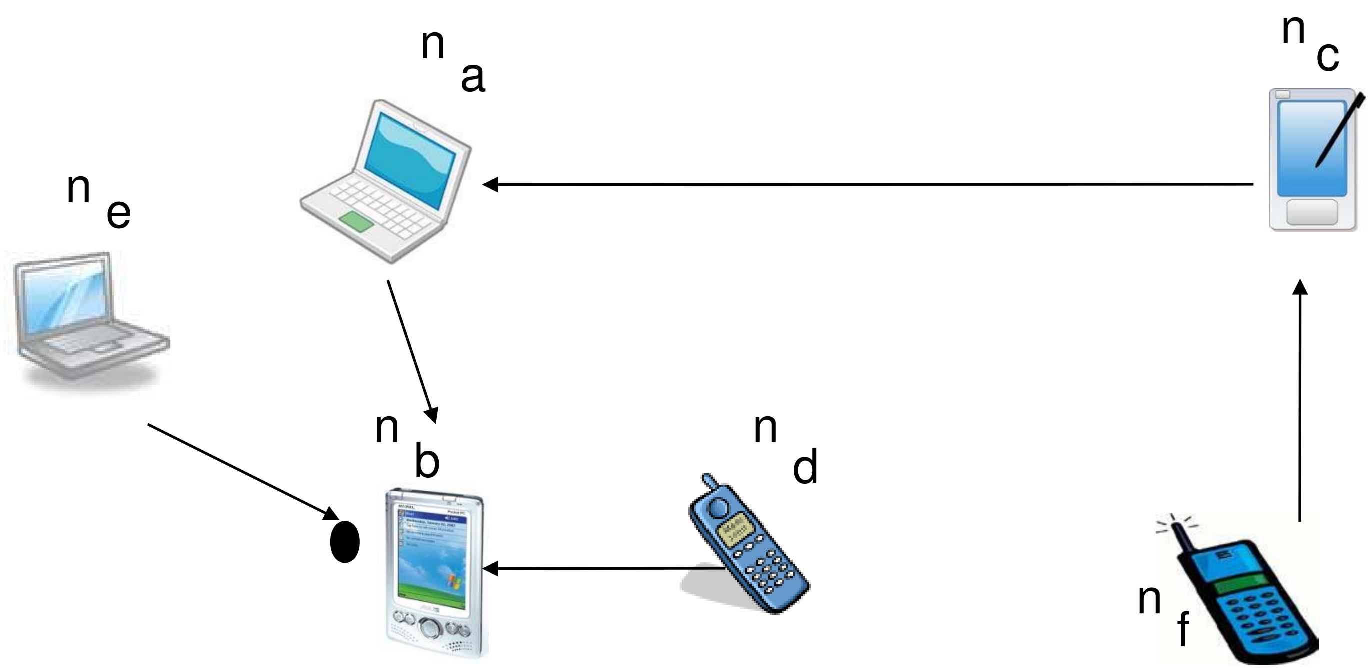
MEOP: Example



MEOP: Example



MEOP: Example



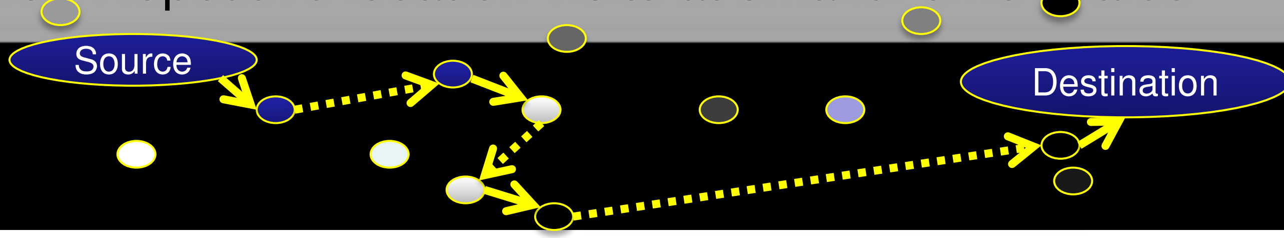
44

Data Diffusion: Problem Statement

To select suitable relays in order to send data across network using opportunistic contacts between mobile users in open environments

Challenges in realistic open environments (parks, streets in a city etc) include

- Delay Tolerance (order of few min to hours)
- Level of Connectivity (partial or sparse - varies with users, location and time)
- Mobility characteristics (some move around in larger space at faster speeds – more *diffusive* as compared to others)
- Changing user behavior (at different locations and times)
- Little interaction history (users may not have any social interaction before)
- Non-Repetitive location visits at smaller time scales



Applications

Transportation

Military

Health

- *Patient monitoring*

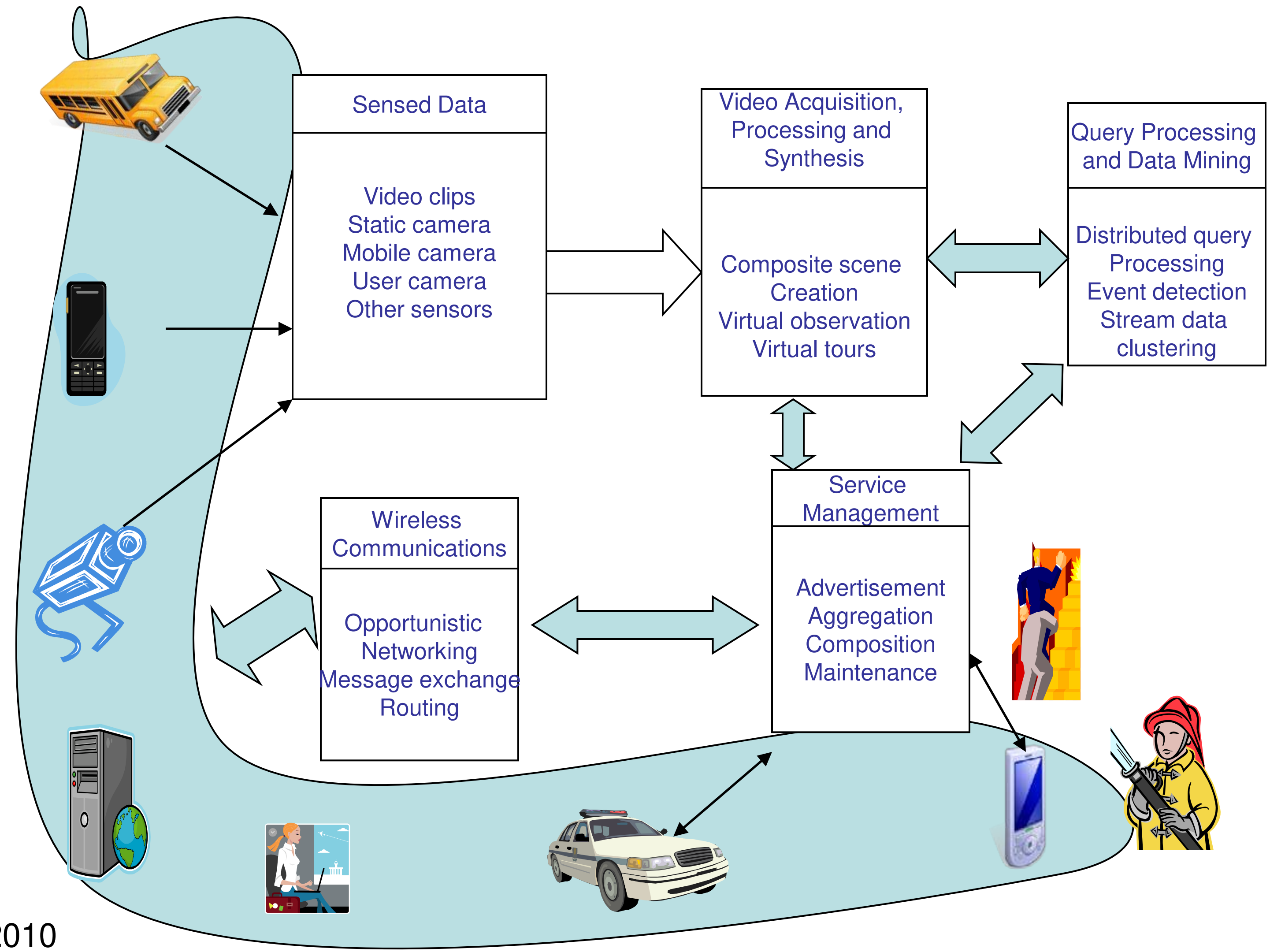
Crisis Management

Entertainment

Mobile Social networking

Marketing

Crisis Management



Conclusions

Distributed Computing on opportunistic networking platform will happen in the near future

Indeed, it is a great opportunity

Path to this goal has many challenges

- *Reliability*
- *Mobility*
- *Fault-tolerance*

Benefit Applications

- *Automatic highways*
- *Health care and preventive measures*
- *Unmanned operations*
- *Entertainment*
- *Crisis management*

Prior Work

Caching, info acquisition and dissemination

- *Optimization, consistency, mobile, distributed, pervasive, P2P*

Active networking in Mobile Environments

- *Mobile IP, buffering packets, split connections*
- *Overlay networks for better services*

Middleware services in Pervasive Systems

- *Creation, composition, maintenance*

Information Fusion

- *Sufficiency and Efficiency*

Data/information sharing in P2P systems

- *Cache optimizations, sharing benefits*

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Projects

- Sharing Information through Publish/Subscribe methods in Opportunistic Networks
- Caching and Pre-fetching Information in Opportunistic Networks
- Service Execution in Opportunistic Networks
- Resource Management in Sensor Systems