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

Security and privacy
- Trust between the two devices/users
- Secure communication channel

Resources on each device

Two devices are within communication range
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

<table>
<thead>
<tr>
<th>Opportunistic connections and paths exist</th>
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<tbody>
<tr>
<td>Resources are distributed in challenged and highly dynamic environments</td>
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<tr>
<td>Cost effective</td>
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<tr>
<td>• <strong>Communicate, distribute when needed</strong></td>
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<tr>
<td>User generated information/events</td>
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<tr>
<td>• <strong>Anywhere, anytime</strong></td>
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<tr>
<td>• <strong>Large</strong></td>
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<tr>
<td>• <strong>Frequent</strong></td>
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<tr>
<td>Automatic filtering</td>
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<tr>
<td>• <strong>Limited buffer space</strong></td>
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<tr>
<td>• <strong>Purge unwanted data</strong></td>
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<td>User-centric applications</td>
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<td>• <strong>Expensive for users to adapt their mobility</strong></td>
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<tr>
<td>• <strong>Limited user attention</strong></td>
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<tr>
<td>Opportunistic computing can be Green</td>
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<tr>
<td>• <strong>Servers, routers, communication channels are not used</strong></td>
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<td>• <strong>Selective Networking</strong></td>
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<td>• <strong>Energy savings</strong></td>
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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
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.

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

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

Opportunistic Computing

- Heterogeneous device and communication technologies
- Pervasive Applications
- Mobile and Ad hoc networking
- Distributed and Fault-tolerant Computing
- Sensor systems
- Pervasive computing
- Middleware services
- Trust, security, Collaboration
- Social Computing
- Opportunistic communications
- Heterogeneous device and communication technologies
- Algorithms, protocols and schemes
- Contexts and profiles

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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

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

Comprises multiple opportunistic contacts

Path delay
- number of contacts
- $\Delta$ is the expected delay for each contact

Intermediate nodes
- Store and forward
- Possess adequate buffer space

Cooperation and collaboration
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

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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? Quality? 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

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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

Distributed Information/database
- Video streams
- Data Streams
- Fused data
- Trust/authentication data

Event and Context Query Processing

User query

Challenge:
User mobility and anonymity
Services and composition

\[ \mathcal{G}_a(s) \]

\[ \mathcal{G}_b(s) \]

\[ \mathcal{G}_{a,b}(s) \]
Service Composition - Example

Distributed Service Composition

Event and Context
Application Profiling
Device Profiling

S1: Observation at Point T1
S2: Observation at Point T2
S3: Collaborative Observation
S4: Render clips for transmission and display on user's PDA
S5: Display service on user device

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
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

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CSE 6349
MEOP: Example
MEOP: Example
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

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Crisis Management

Sensed Data
- Video clips
- Static camera
- Mobile camera
- User camera
- Other sensors

Video Acquisition, Processing and Synthesis
- Composite scene
- Creation
- Virtual observation
- Virtual tours

Query Processing and Data Mining
- Distributed query
- Processing
- Event detection
- Stream data
- Clustering

Service Management
- Advertisement
- Aggregation
- Composition
- Maintenance

Wireless Communications
- Opportunistic Networking
- Message exchange
- Routing
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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Peng Yang, Mooi Choo Chuah, “Context Aware Multicast Routing Scheme for Disruption Tolerant Networks”, PE-WASUN’06, October 6, 2006, Torremolinos, Malaga Spain, pp. 66-73.
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