# Mobility and Multiaccess in Emerging Internet Architectures

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# Abstract

*Popular mobile devices now ship with several integrated wired and wireless network interfaces. As multiaccess devices proliferate, we move closer to a network environment that is often referred to as “beyond 3G”, or B3G in telecommunications speak. This tutorial thoroughly reviews recent developments in mobility and multiaccess technologies and presents recent work in this area, focusing in particular on results from large European Integrated Projects. In order to optimize the use of available network resources, mobile nodes need to be able to collect information on a number of heterogeneous networks in a generic and standardized way, irrespective of the underlying network access technology. After motivating the need for novel mechanisms to meet the challenges from the emerging network environment, we introduce the long-awaited Media Independent Handover Services standard (IEEE 802.21) and discuss implementation aspects. Finally, we introduce recent developments in the so-called clean-slate Internet architecture design space, presenting new paradigms, and elaborating on their impact on mobility and multiaccess. The aim is to revolutionize the current way of communication over wireless networks for mobile applications.*

# Tutorial Outline (1/4)

- From Mobile IP to Mobile Networks to “Mobile Memory Sticks”?
- From GSM Dominance to Always Best Connected
- Ambient Networks
- Mobility Trigger Management

# Tutorial Outline (2/4)

- TRG: A Trigger Management Implementation
- Trigger Temporal Correlation and Chronicle Recognition
- ANISI: Ambient Networks Information Service Infrastructure
- ANHASA: Ambient Networks Heterogeneous Access Selection

# Tutorial Outline (3/4)

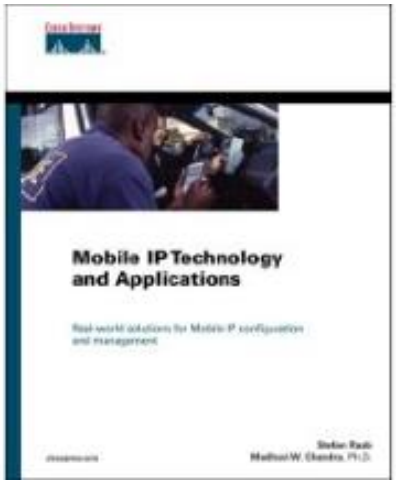
- IEEE 802.21 Media Independent Handover Services
  - Scope and Purpose
  - Example use case
  - Implementation
- Towards Energy-efficient System Designs
- Information Distribution in Dynamic Networks

# Tutorial Outline (4/4)

- The Changing Nature of Multiaccess
- Content Delivery in a Mobile Wireless World
- 4WARD
  - Architecture and Design for the Future Internet
- Towards information-centric networking

# From Mobile IP to Mobile Networks to “Mobile Memory Sticks”?

- What this tutorial is not about:




  - See ICN 2008 Tutorial titled *Mobility: An Inside Perspective from Telecom Operators* by P. Vidales and C. Policroniades

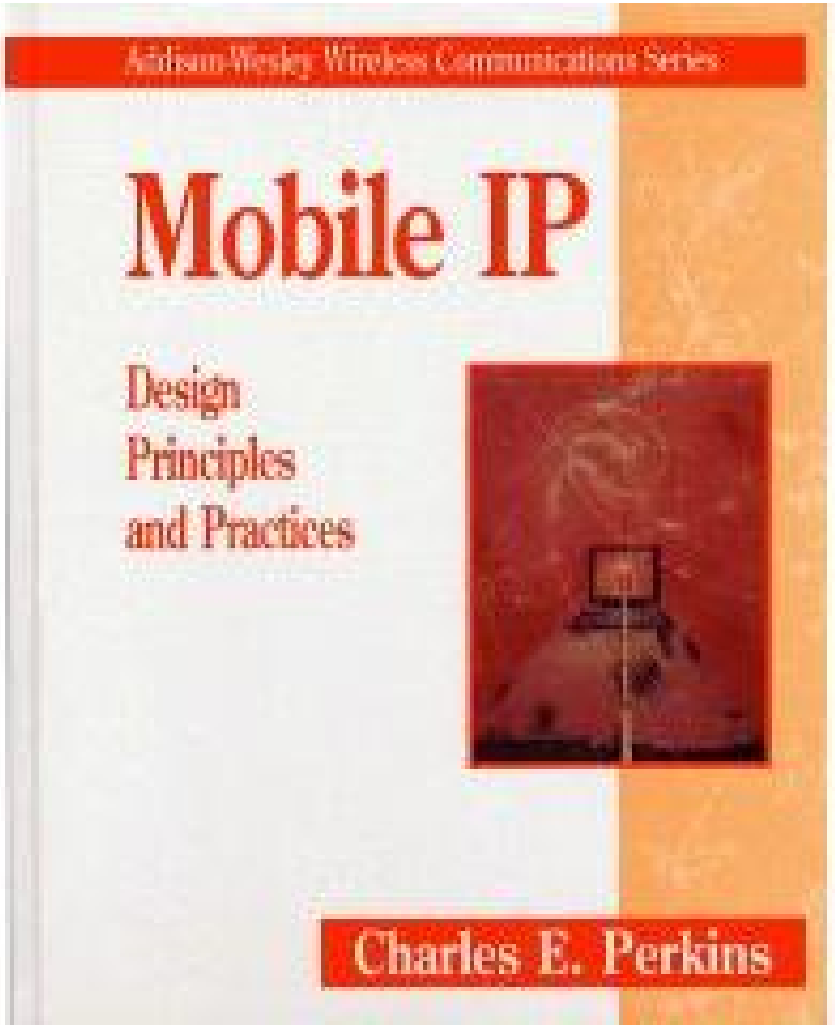
# What does **Mobile Networking** Mean, Exactly?

- Indeed, what exactly does “mobile Internet” mean to you?
  - Mobile IP?
  - WAP?
  - NEMO? PMIP? FMIP?
  - HIP?
  - GSM?
  - 3G, LTE, SAE?
  - WiMAX?
  - …
- So let’s start with a bit of history

# 1996-7: Mobile IP Becomes the Next BIG Thing

- October 1996: *IP Mobility Support* (RFC 2002)
- November 1996: “Mobility Support in IPv6” is presented at MobiCom in a session titled *Mobile and Wireless TCP/IP*
- November 1997: *Mobile IP, Design Principles and Practices* by C. E. Perkins comes out

# 1996-7: Mobile IP Becomes the Next BIG Thing



# Flashback: “Mobile Nodes” in 1997

- PowerBook G3 (November 1997)
  - Original Price: US$5700
  - CPU: G3 processor 250 MHz
  - Display: 12.1" TFT SVGA (800 x 600 pixels)
  - Memory: “32 MB of RAM, 2 MB of VRAM, 5 GB HDD, and a 20X tray-loading CD-ROM”
  - Networking: 10Base-T (no Wi-Fi, BT, not even Firewire)
- Mobile phones:
  - Motorola V3688
  - Nokia 3110

# Flashback: “Mobile Nodes” in 1997

# PowerBook G3 *vs.* Nokia N95

| | **G3 (1997)** | **N95 (2007)** |
|---|---|---|
| Primary Memory (MB) | 32 | 160 |
| CPU | G3 250 MHz | ARM v11 333 MHz |
| Secondary storage (GB) | 5 + CDROM | … 8 (MicroSDHC) |
| Networking | 10Base-T Ethernet | GSM, GPRS, EDGE, WCDMA, HSDPA<br>Bluetooth, IrDA<br>IEEE 802.11 b/g |

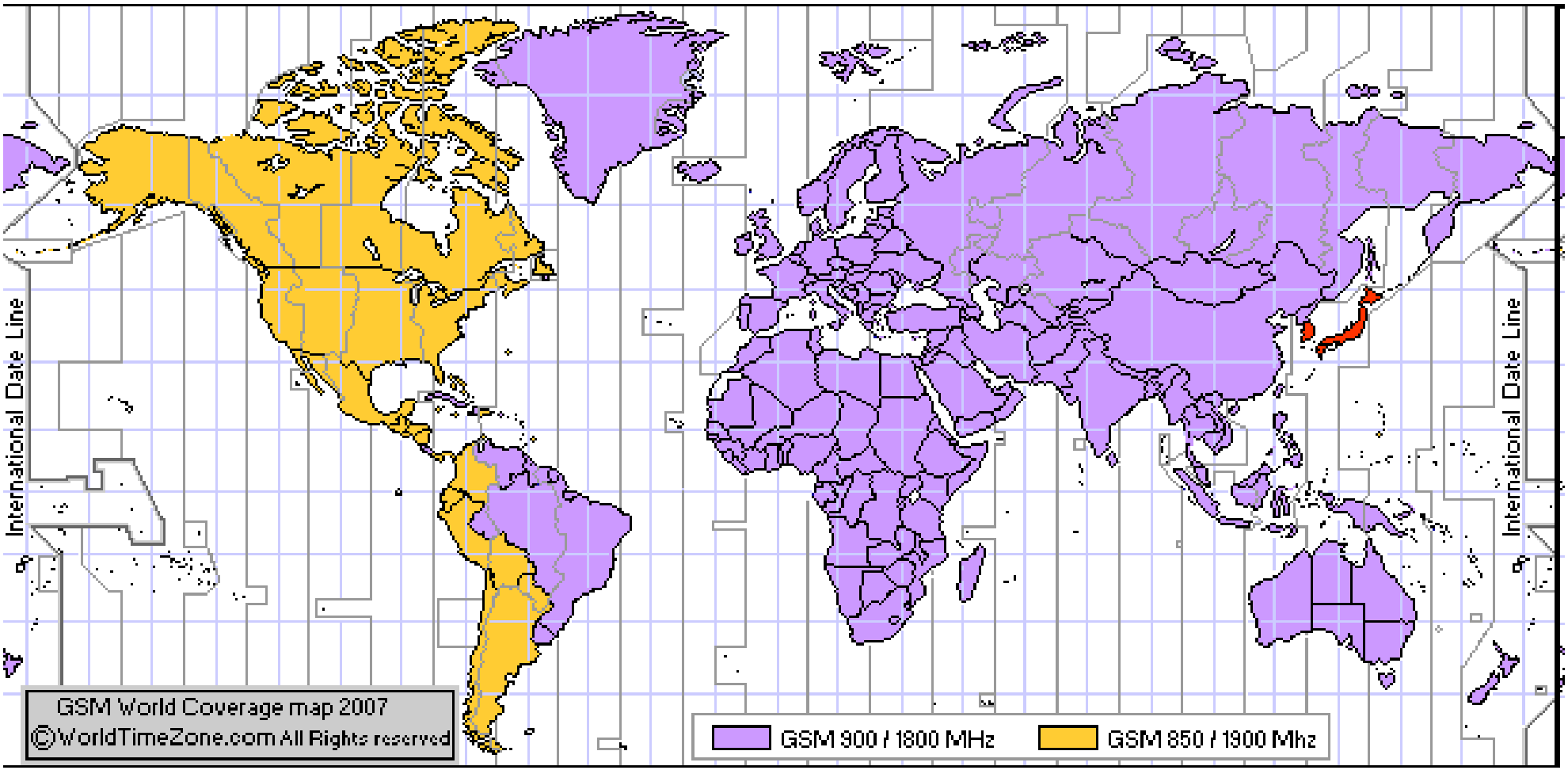
# But Something New is on the Horizon

- GSM Phase 2+ standard is finalized: GPRS arrives, then EDGE, ...
  - C. Bettstetter, H.-J. Vogel, and J. Eberspacher, "GSM phase 2+ general packet radio service GPRS: Architecture, protocols, and air interface," *IEEE Communications Surveys & Tutorials*, **2**(3), pp. 2-14, 1999
  - T. Ojanpera and R. Prasad, *WCDMA: Towards IP Mobility and Mobile Internet*. Boston, Massachusetts, USA: Artech House, 2001

# 1997-2008: GSM Cellular Takes Over

- Growth in GSM
  - 2 – 2,000,000,000 connected devices in 15 years
    - More than 3 billion today?
  - 10 kb/s – 14000 kb/s in 10 years
  - GSM, GPRS, EDGE, 3G/WCDMA, HSPA, LTE,..
  - 860 networks in 220 countries/areas of the world

# 1997-2008: GSM Cellular Takes Over



# Today, 3GPP Standards Dominate

engadget

## Verizon dumps CDMA for GSM-based LTE in 4G networks

by Chris Ziegler, posted Sep 21st 2007 at 12:28PM

Just a few months removed from rumors that Vodafone would offload its stake in Verizon Wireless altogether, the two networks have announced that they'll share a common selection for their fourth-generation data networks: Long-Term Evolution. Endorsed by the 3GPP as the official way to burn wireless rubber in the next few years, LTE is a progression of GSM's UMTS platform, making it an ironic choice for CDMA stalwart Verizon and a huge blow for the CDMA Development Group's competing UMB standard. It seems that the unusual move was influenced by the fact that the sister networks -- two of the world's largest -- should probably enjoy *some* semblance of technological synergy if they're going to carry on their blissful matrimony for the foreseeable future, with Verizon CEO Ivan Seidenberg saying the company has been looking for "stability" in the relationship. Whatever the case, don't throw away that brand spanking new VX8550 or anything rash like that -- the companies aren't looking to roll anything out for another three or four years.

verizon wireless

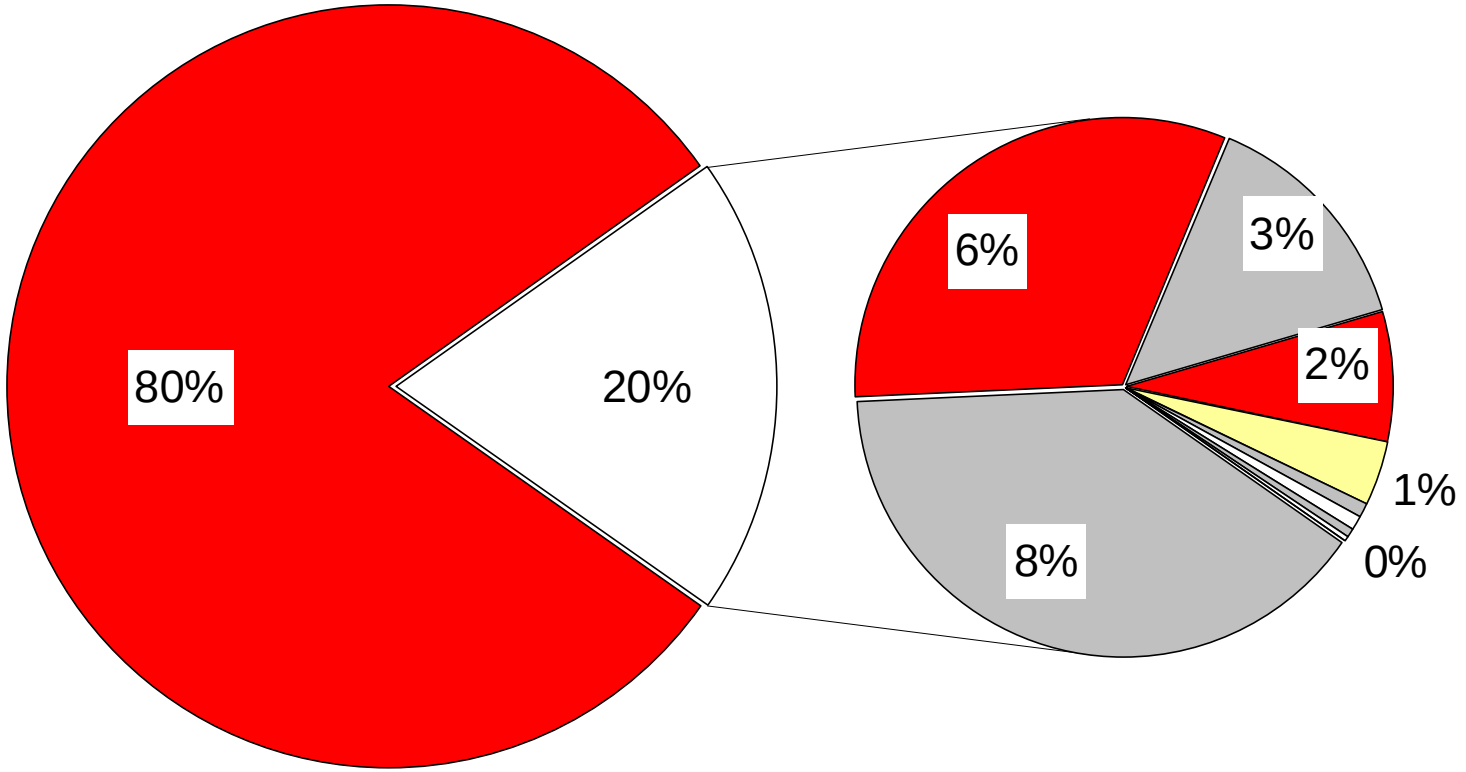
cellular-news

According to a recent briefing from the *Mobile World*, the number of CDMA mobile customers in CALA (Caribbean and Latin America) has plummeted by almost 13m in the year to 31st March 2008, ending on 50.6m, after a seventh successive quarter of decline in Q1 08.

CANTV in Venezuela is the last remaining CDMA operator in the Caribbean and Latin America region not to also have an active GSM network (excepting a handful of very small providers in markets such as Belize and the Cayman Islands) and even here a launch is due later in the year.

Posted to the site on 24th November 2008

# 3GPP Domination: Q3 2008




Mobile Infolink

22.9.2008

# Global Reachability Attained… Now What?


- *IEEE Wireless Communications,* **10**(1), February 2003, pp. 49-55
- "The always best connected (ABC) concept allows a person connectivity to applications using the devices and access technologies that best suit his or her needs, thereby combining the features of access technologies such as DSL, Bluetooth, and WLAN with cellular systems to provide an enhanced user experience for 2.5G, 3G, and beyond."

# Several EU Projects Worked on ABC

- Ambient Networks
- DAIDALOS
- MAGNET
- ...
- SATSIX
- …
- WEIRD
- …
- Plus several national projects (e.g. MERCoNe in Finland)
- Plus numerous Doctoral Dissertations and Master Theses





# So What Was Achieved Over the Last 6 Years?

- A lot! But we still have to see products in the market place
- Don’t throw your demos out of the window
  - Companies will come asking for solutions, soon
- If your professor asked you to work on topics in this area, make sure you read all seminal previous work!
  - Lots of proposals, new grads need to do significant background reading
  - Lots of projects, demos, proves-of-concept
  - Lots of papers, conferences, special issues, book chapters
- This tutorial is a good start
  - But focuses mainly on Ambient Networks, due to temporal restriction

# The Ambient Networks Project

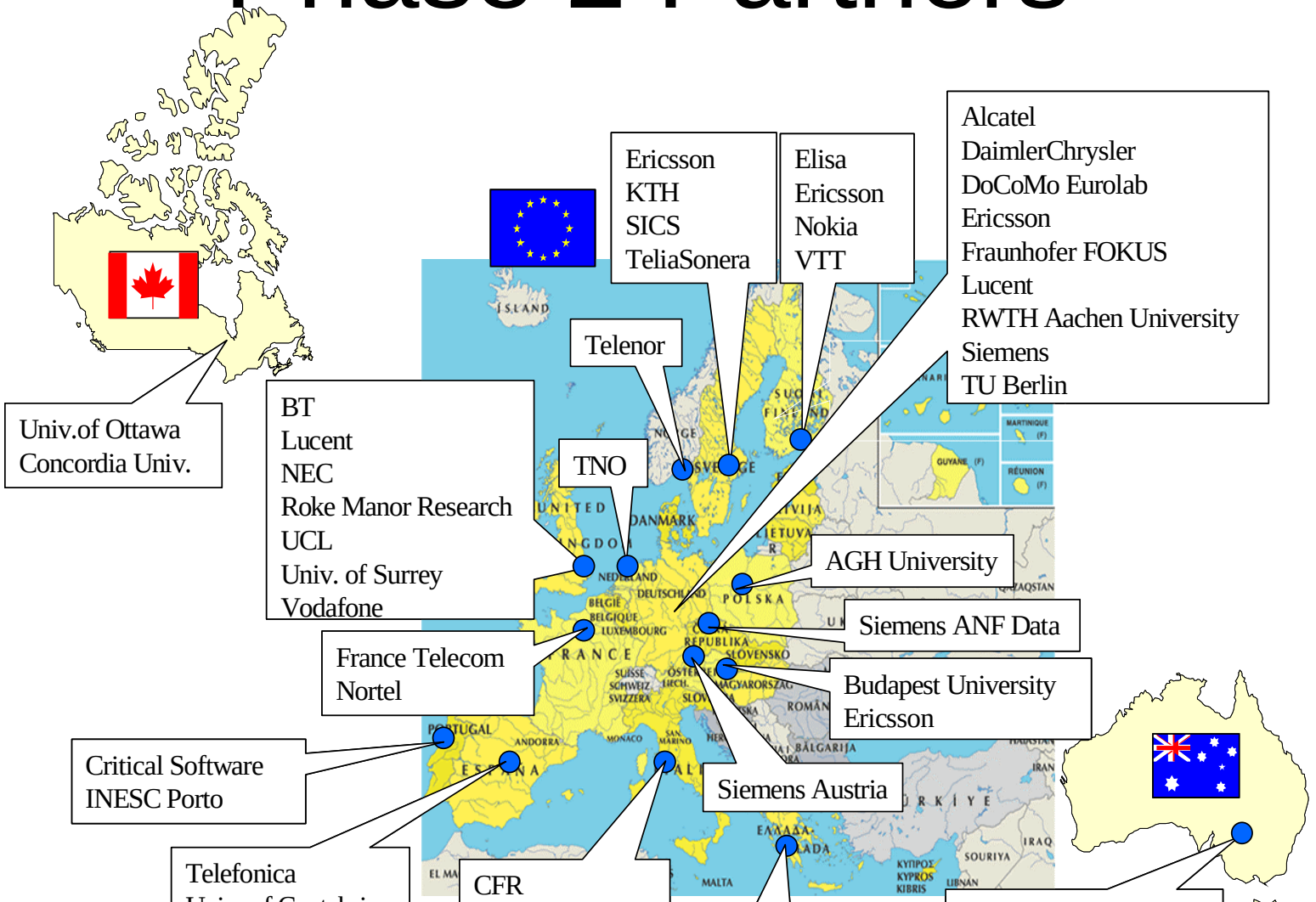
- Integrated Project in EU 6th Framework Programme; 50% EU contribution; Legal framework
- Phase 1: 2004-2005; Size: 22 Meuro, 190 person years
- Phase 2: 2006-2007; Size: same as Phase 1
  - 35+ partners: 10 Vendors; 10 Operators; 15 Academia
- Coordinated by : Ericsson AB
- Part of the Wireless World Initiative (WWI)

# The Ambient Networks Project

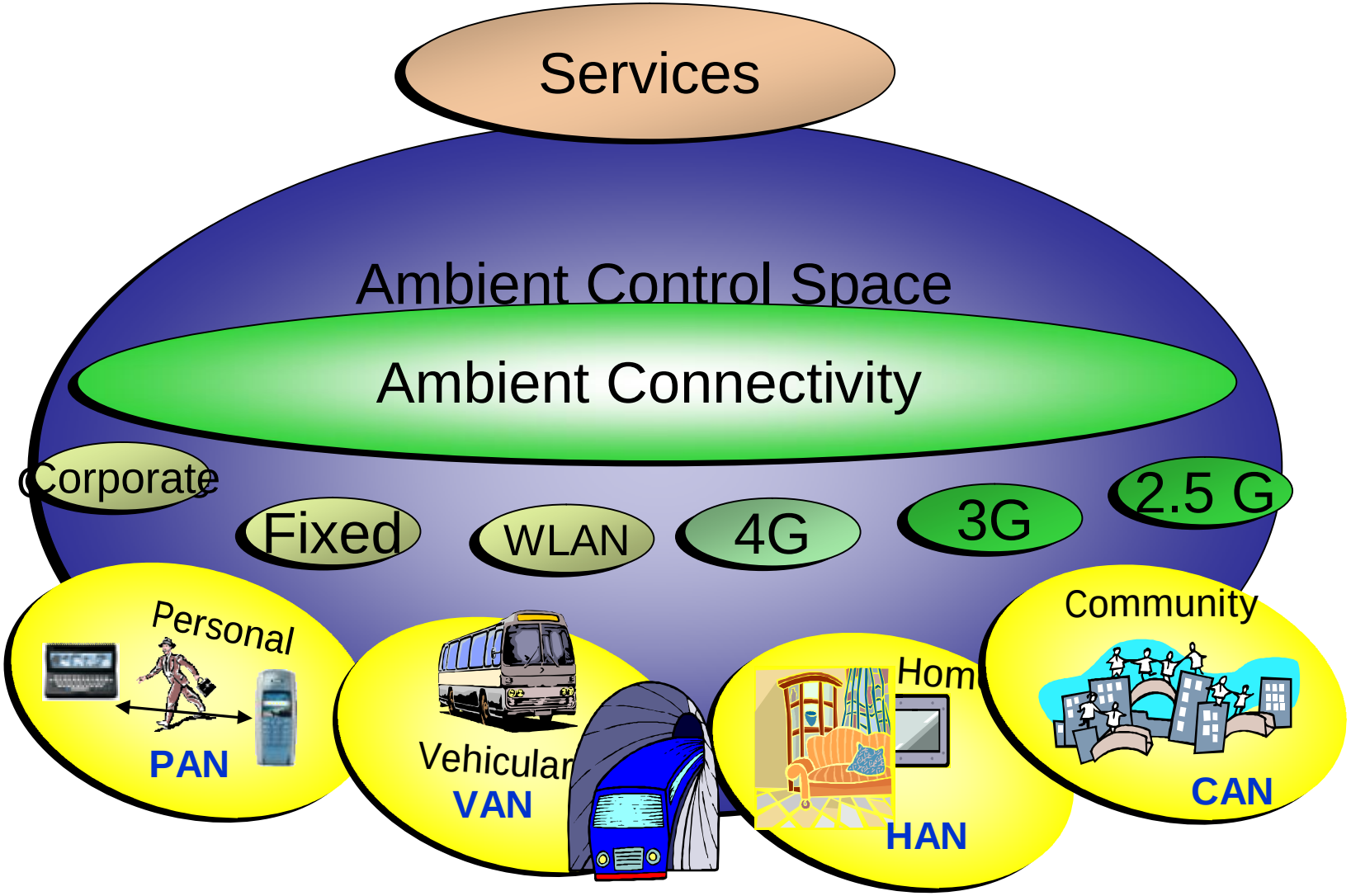
- Research areas:

  - Architecture
  - Multi-access
  - Composition
  - Mobility
  - Media Delivery
  - Context Management
  - Security
  - Network Management

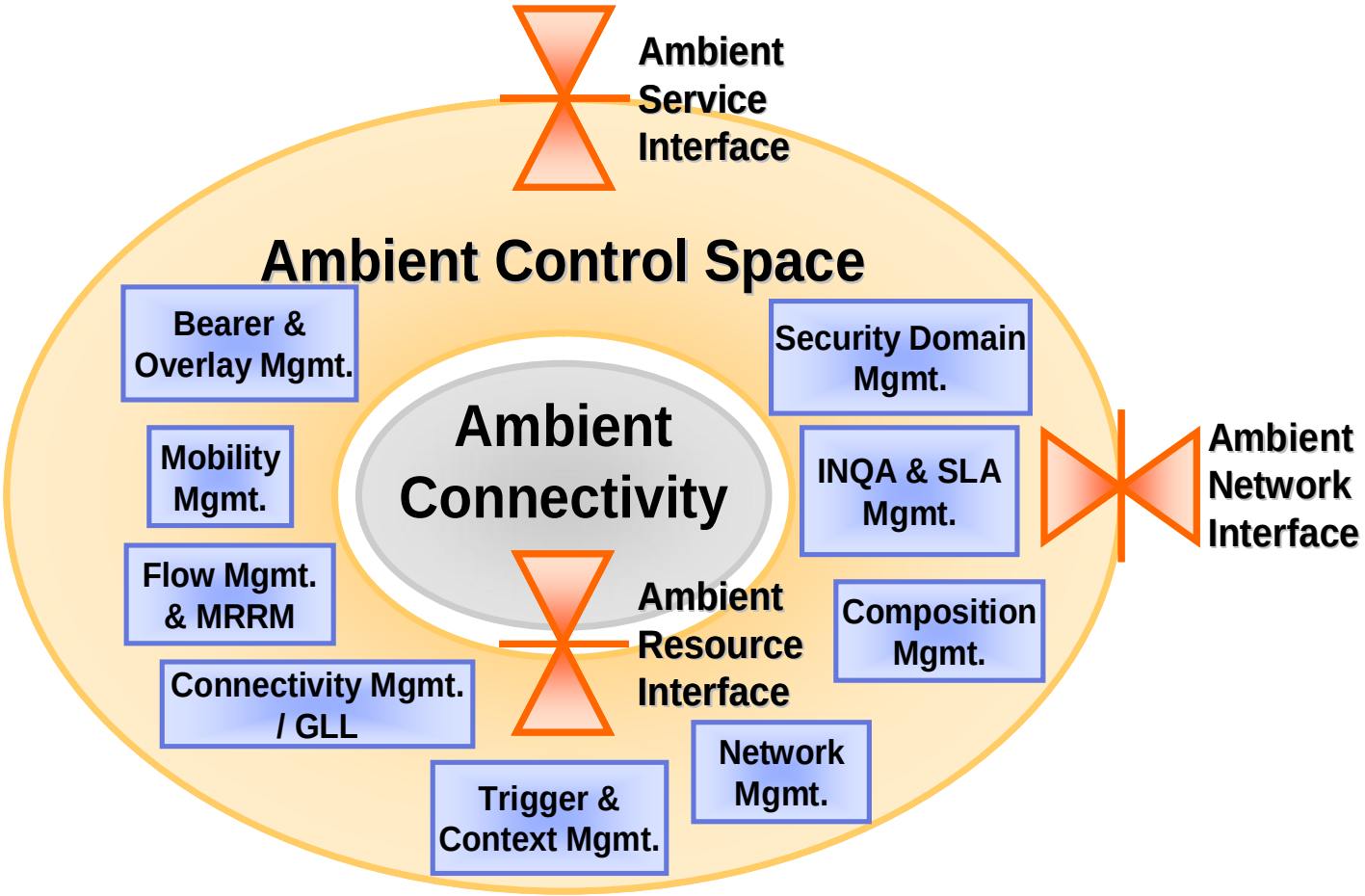

# The Ambient Networks Project: Phase 2 Partners



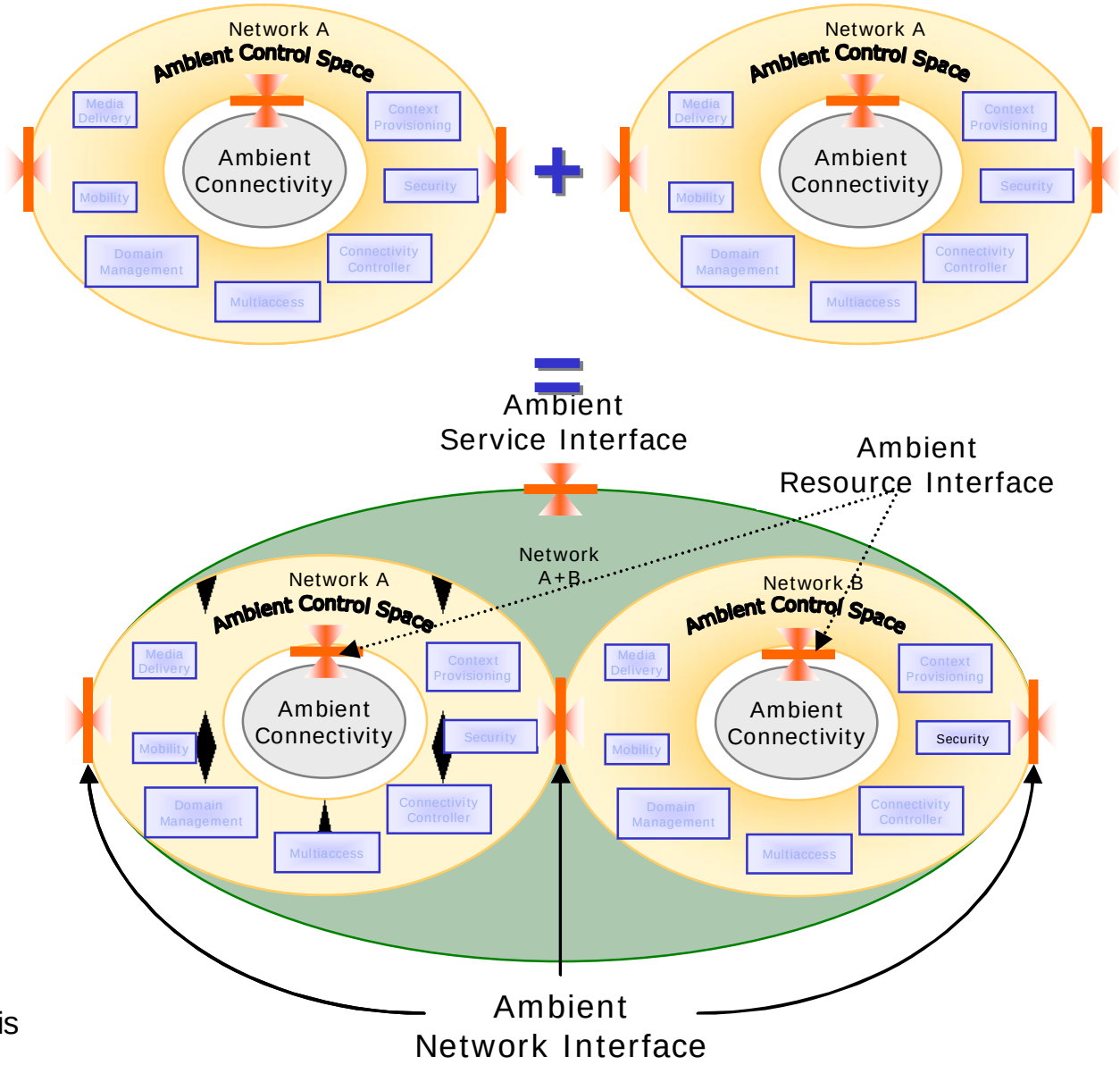
# Ambient Networks Concept



# Ambient Control Space



# Ambient Networks Composition and Reference Points



# Further Reading

- N. Niebert, A. Schieder, J. Zander, and R. Hancock, Eds., *Ambient Networks: Co-operative Mobile Networking for the Wireless World*. Wiley, 2007.
- *AN System Description*, Ambient Networks Phase 2 (IST 027662), Public Deliverable D18-A.4, December 2007.
- *Mobility Support: System Specification, Implementation and Evaluation*, Ambient Networks Phase 2 (IST 027662), Public Deliverable D20-B.2, December 2007.

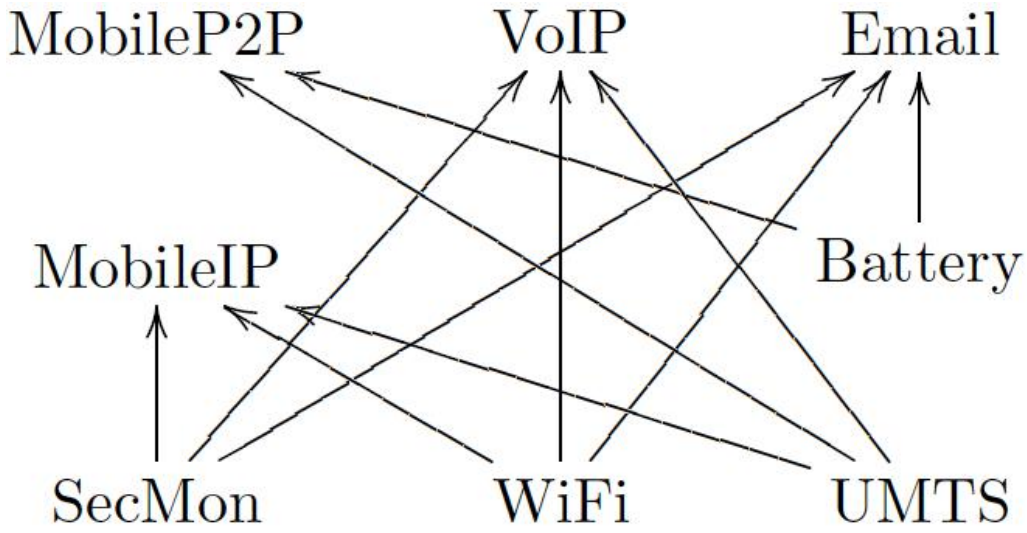
# Mobility Management in


- Take advantage of many networks in parallel
- Communication becomes complex
  - Mobility for flows, sessions, groups of devices
    - Mobility patterns as a factor in forming networks
    - Composability and Security/Trust
    - Scalability and Reliability
  - Multi-radio resource management
    - Now: BT, Wi-Fi, 3G/UMTS/HSPA; soon: WiMax,…
  - Multi-mobility management protocols
    - Now: MIPv4/v6/NEMO, SIP; next: HIP, NodeID, post-IP
  - User context, ad-hoc network formations

# Information Management for Dynamic Networks

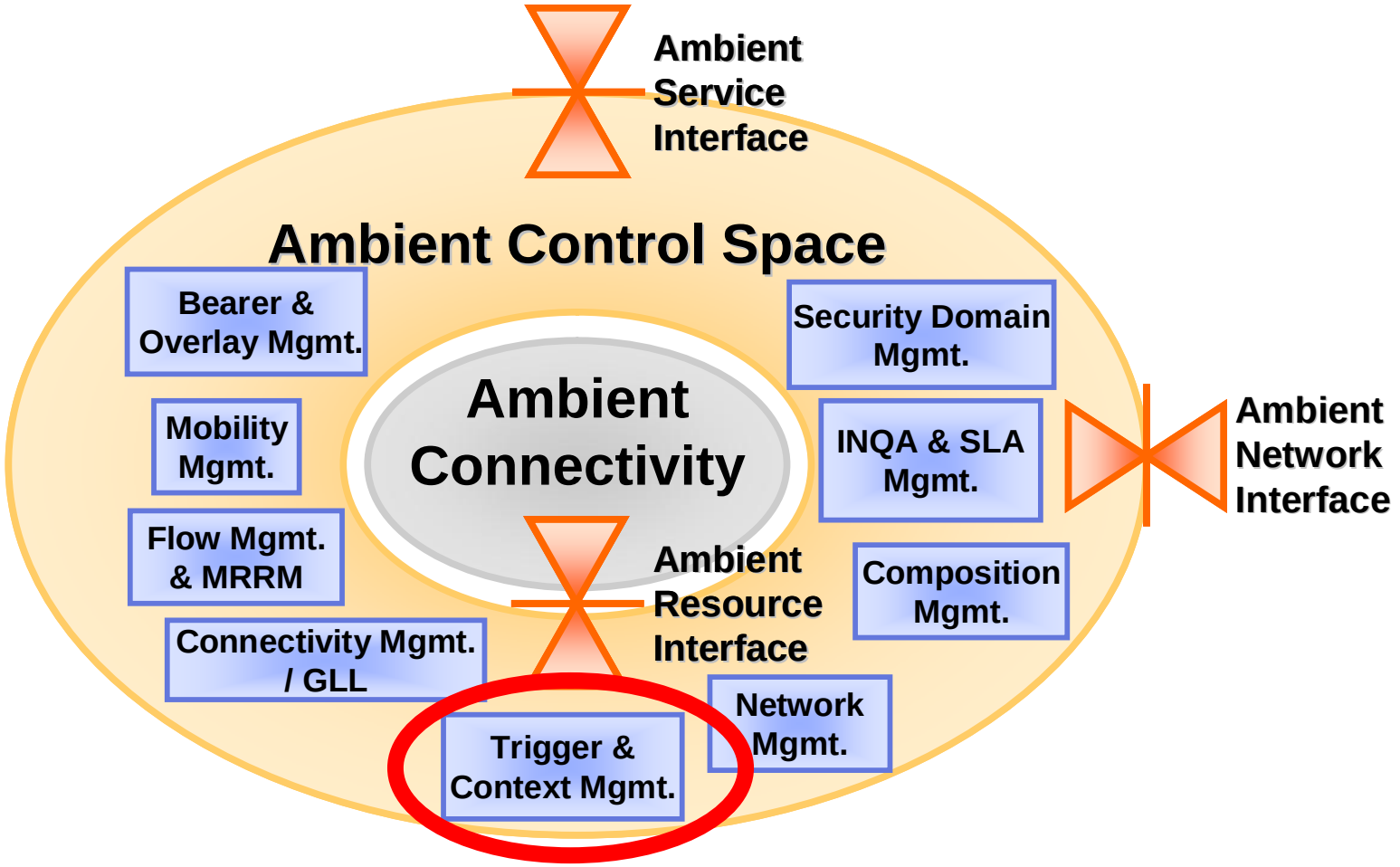
- Drivers
  - Proliferation of multi-interface devices leads to complexity
  - Best-connected paradigm becomes prevalent
  - Network solutions should have several self-X properties
  - Ambient Control Space
- Support
  - enhanced mobility management, beyond host mobility
  - context-aware communications in today's pervasive networking environment
  - multi-operator environment
- Provide the means for gathering, correlating, and managing cross-layer and cross-domain information

# Today: Convoluted Information Flows




- Different event **sources** can provide information regarding mobility
- Different system components and applications
  - may be interested in the same or similar **information**,
  - but each one must, in **isolation**, acquire data, create a knowledge base, and maintain it
- Wanted: **single point of reference**, a reliable source of triggers

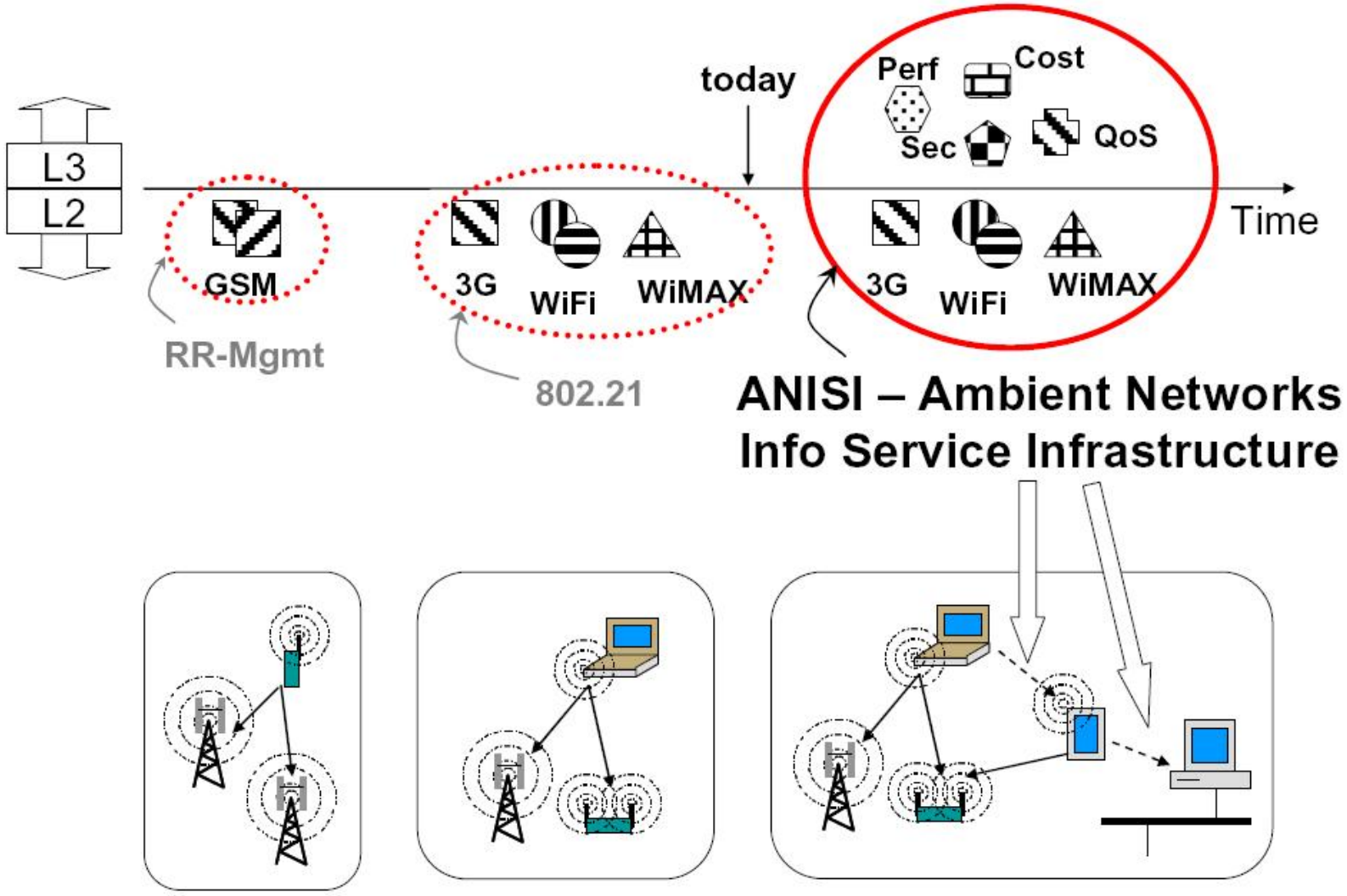
# Trigger Management in the Ambient Control Space



# What is a Trigger?

- The term *trigger* refers to a notification about changes regarding mobility, including, for example
  - SNR, RSSI, cell load, utilization, packet drops, …
  - Routing updates, availability
  - Policy violations, security alerts
  - Changes in charging, cost
  - Changes in user context/preferences
  - Processor load, storage quotas, battery state of charge
- Well beyond what IEEE 802.21 can deliver

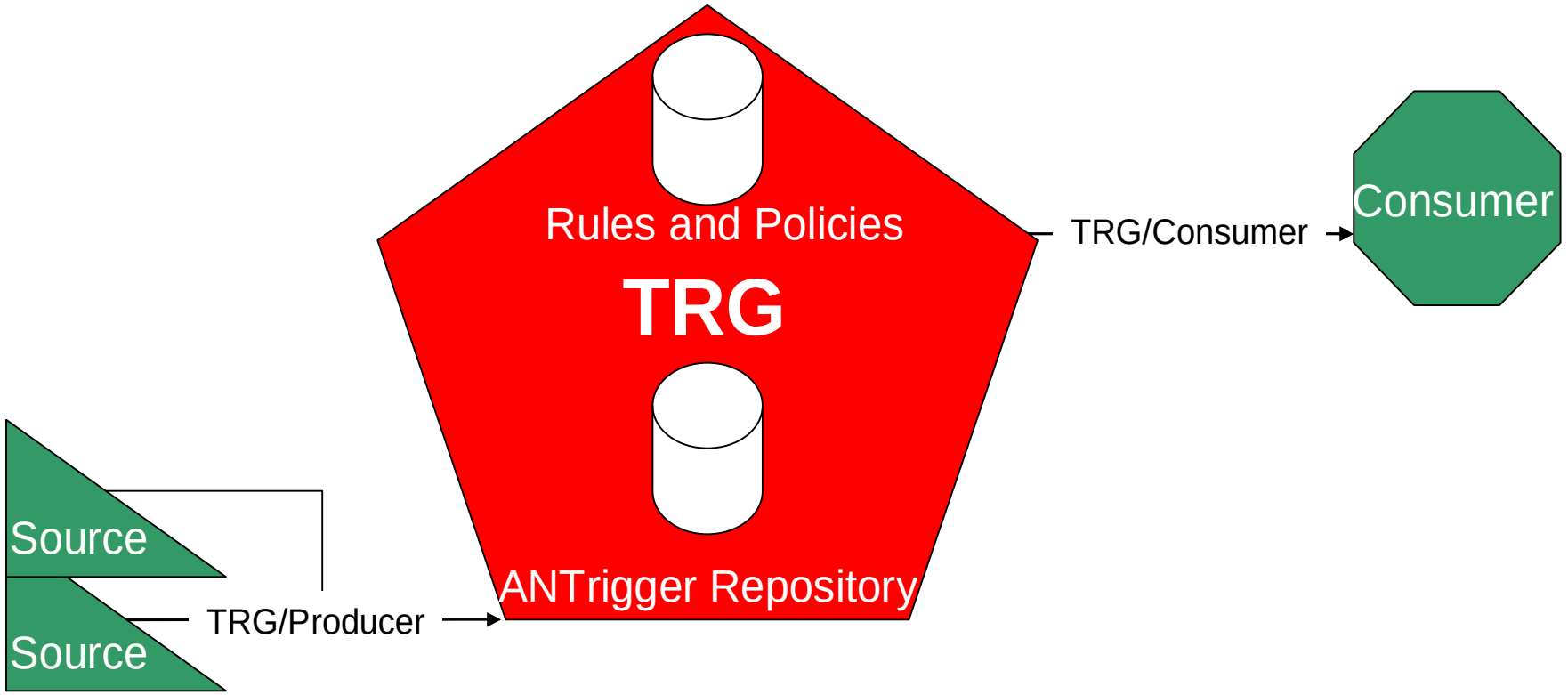
# Information Services for Handover Support



# Further Reading

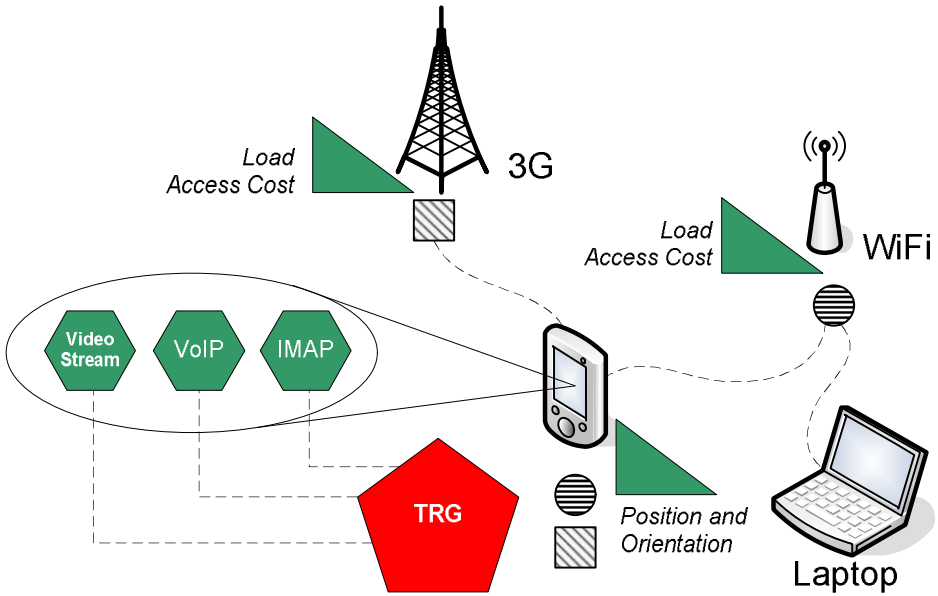
- R. Giaffreda, K. Pentikousis, E. Hepworth, R. Agüero, and A. Galis, “An information service infrastructure for Ambient Networks”, *Proc. 25th International Conference on Parallel and Distributed Computing and Networks* (PDCN), Innsbruck, Austria, February 2007, pp. 21–27
- *Mobility Support: System Specification, Implementation and Evaluation*, Ambient Networks Phase 2 (IST 027662), Public Deliverable D20-B.2, December 2007

# Trigger Management: The Big Picture

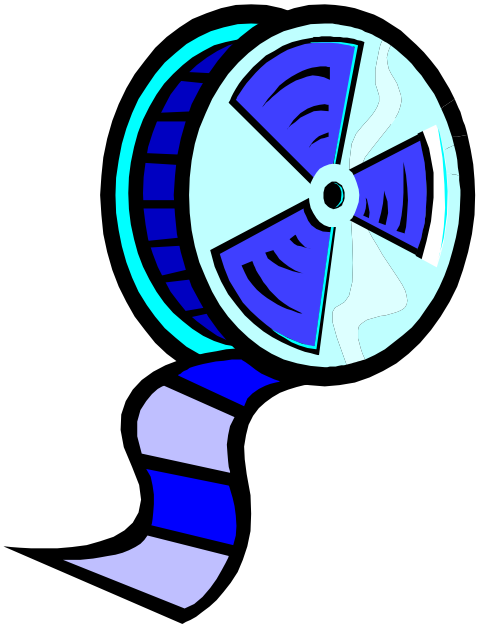


# Mobility Triggers in Practice

- We demonstrated how to deliver triggers to HIP, MIP, and video streaming applications, filtered based on consumer preferences




# Mobility Triggers in Practice



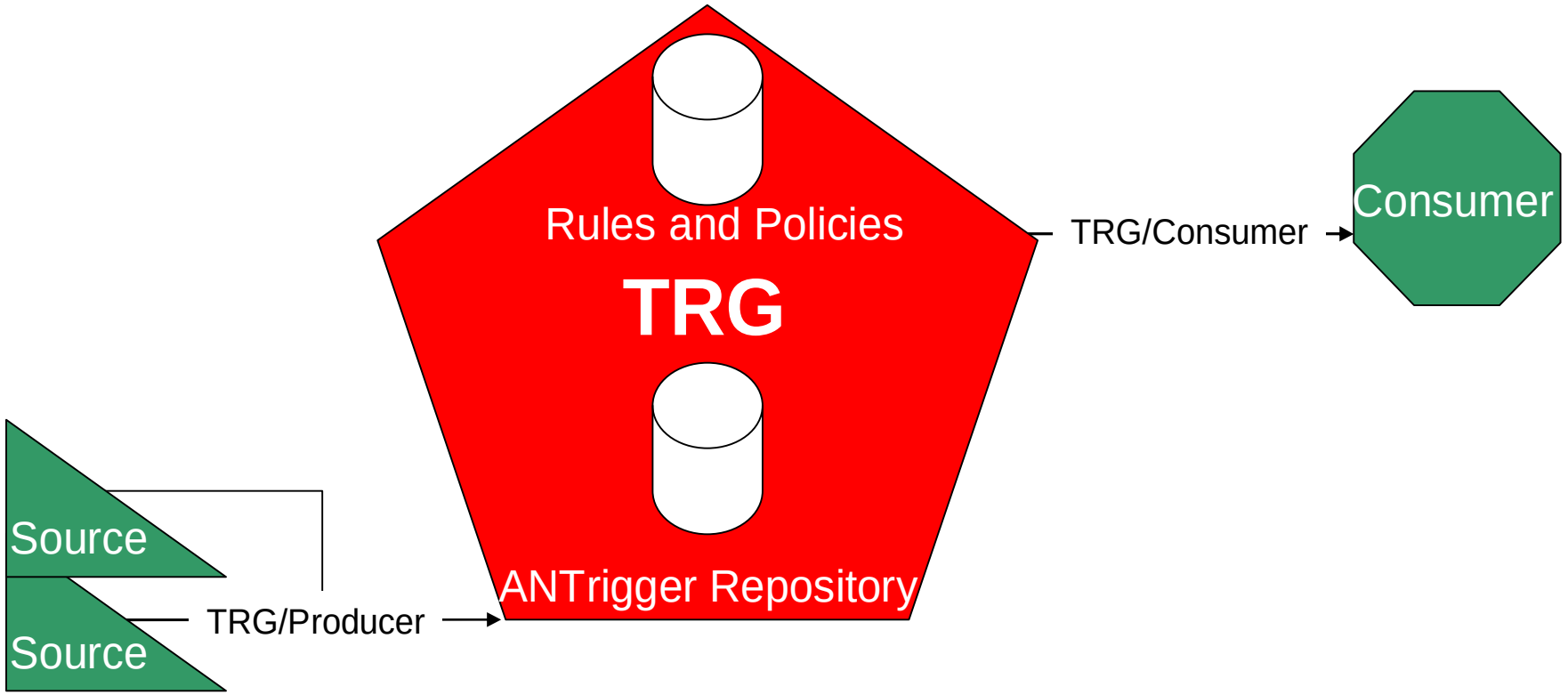
# Further Reading


- J. Mäkelä, R. Aguero, J. Tenhunen, V. Kyllnen, J. Choque, and L. Munoz, “Paving the Way for Future Mobility Mechanisms: A Testbed for Mobility Triggering & Moving Network Support,” in *Proc. TridentCom*, Barcelona, Spain, March 2006.
- J. Mäkelä and K. Pentikousis, “Trigger management mechanisms”, *Proc. Second International Symposium on Wireless Pervasive Computing* (ISWPC), San Juan, Puerto Rico, USA, February 2007, pp. 378–383.
- P. Pääkkönen, P. Salmela, R. Aguero, and J. Choque, “An integrated Ambient Networks prototype”, *Proc. International Conference on Software, Telecommunications and Computer Networks* (SoftCOM), Split, Croatia, September 2007.

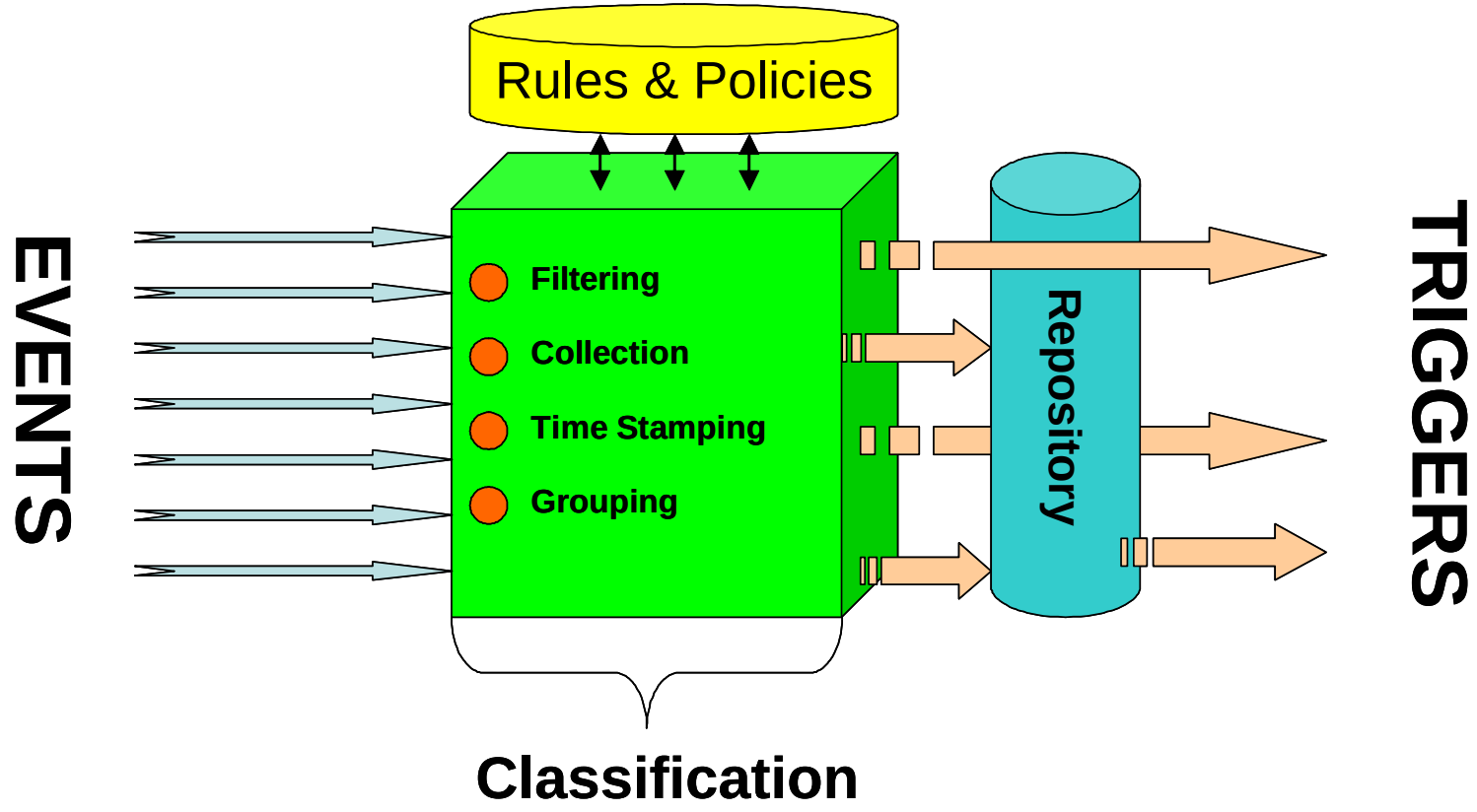
# Tutorial Outline (2/4)

- TRG: A Trigger Management Implementation
- Trigger Temporal Correlation and Chronicle Recognition
- ANISI: Ambient Networks Information Service Infrastructure
- ANHASA: Ambient Networks Heterogeneous Access Selection

# Trigger Management: The Big Picture

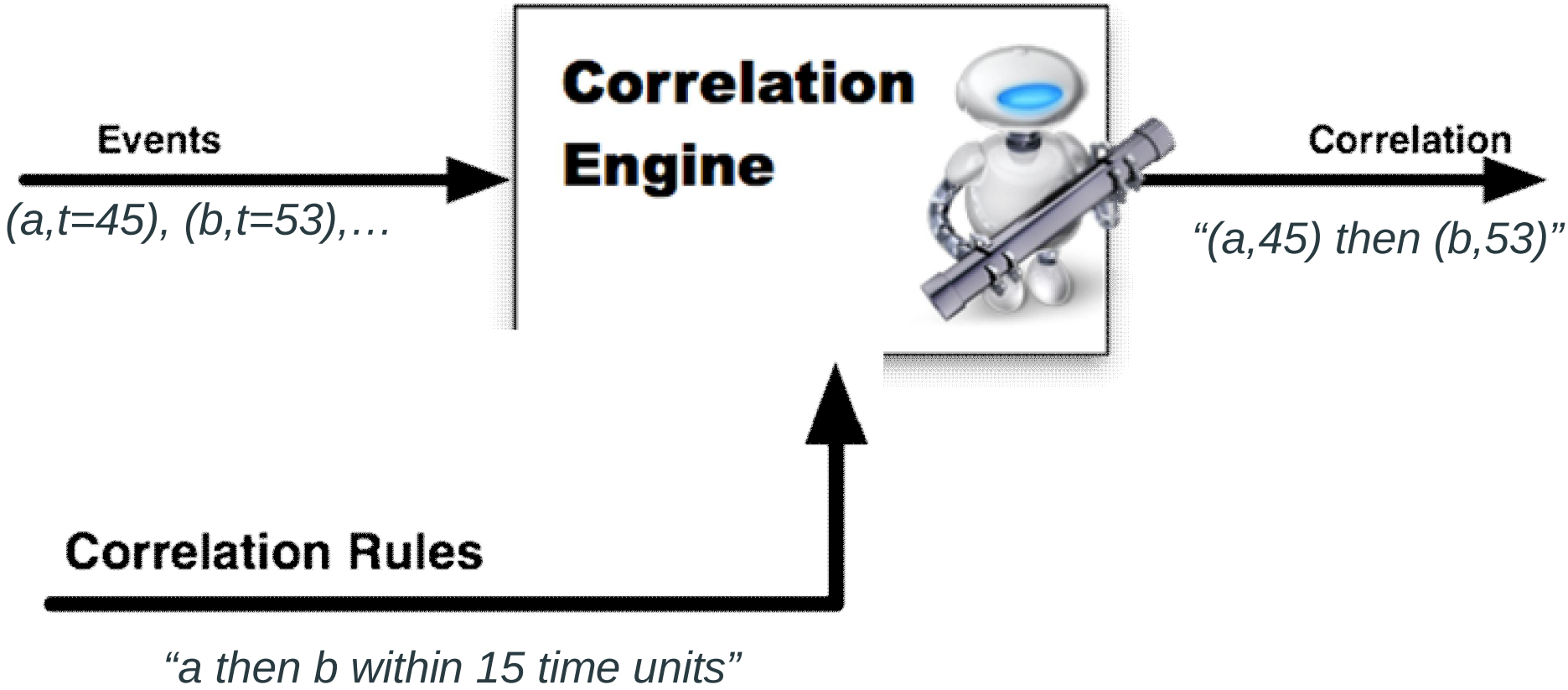


# TRG: A Trigger Management Implementation




- J. Mäkelä and K. Pentikousis, “Trigger management mechanisms”, *Proc. Second International Symposium on Wireless Pervasive Computing* (ISWPC), San Juan, Puerto Rico, USA, February 2007, pp. 378–383.

# Temporal Correlation and Chronicle Recognition




- C. Dousson, K. Pentikousis, T. Sutinen, and J. Mäkelä, "Chronicle recognition for mobility management triggers", *Proc. 12th IEEE Symposium on Computers and Communications* (ISCC), Aveiro, Portugal, July 2007, pp. 305–310.

# Detecting an Unstable Link (1/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- First, define a chronicle for a single link up/down (LUD) event

```
chronicle LUD(t1) {



}
```

# Detecting an Unstable Link (2/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- First, define a chronicle for a single **link up**/down (LUD) event

```
chronicle LUD(t1) {
  event(link:(down, up), t1) # trigger



}
```

# Detecting an Unstable Link (3/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- First, define a chronicle for a single **link** up/**down** (LUD) event

```
chronicle LUD(t1) {
  event(link:(down, up), t1)
  event(link:(up, down), t2) # trigger


}
```

# Detecting an Unstable Link (4/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- First, define a chronicle for a **single link up/down** (LUD) event

```
chronicle LUD(t1) {
  event(link:(down, up), t1)
  event(link:(up, down), t2)
  hold(link:good, (t1, t2-1))
  0 < t2 - t1 < 5
}
```

# Detecting an Unstable Link (5/10)

- Problem: **Detect** the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an **unstable link**
- Then, recognize two sequences only if the time between them is at least 60s:

```
chronicle LinkUnstable {




}
```

# Detecting an Unstable Link (6/10)

- Problem: Detect the start sequence of, at least, **three consecutive "link up/down"** triggers within 30s, which is good indication of an unstable link
- Then, recognize two sequences only if the time between them is at least 60s:

```
chronicle LinkUnstable {
   event(LUD,t1) # chronicle recognition = synthetic trigger
   event(LUD,t2) # ditto
   event(LUD,t3) # ditto


}
```

# Detecting an Unstable Link (7/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers **within 30s**, which is good indication of an unstable link
- Then, recognize two sequences only if the time between them is at least 60s:

```
chronicle LinkUnstable {
  event(LUD,t1)
  event(LUD,t2)
  event(LUD,t3)

  t3 - t1 < 30
}
```

# Detecting an Unstable Link (8/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- Then, recognize **two sequences** only if the time between them is at least **60s**:

```
chronicle LinkUnstable {
  event(LUD,t1) noevent(LUD,(t1-60,t1-1))
  event(LUD,t2)
  event(LUD,t3)
  t1 < t2 < t3
  t3 - t1 < 30
}
```

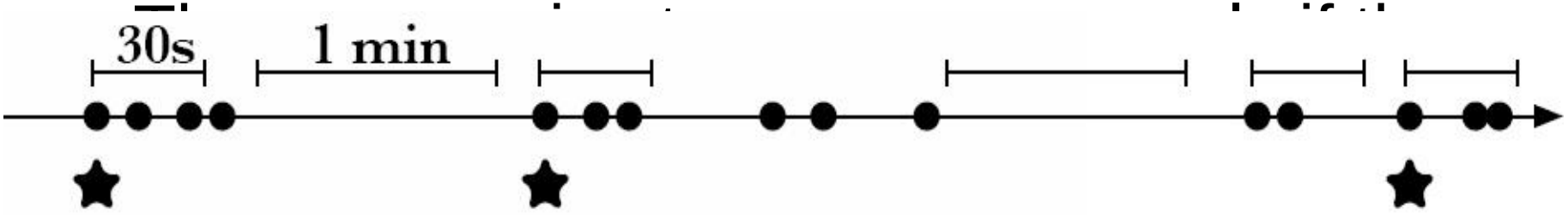
# Detecting an Unstable Link (9/10)

- Problem: Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
- Then, recognize two sequences only if the time between them is at least 60s:

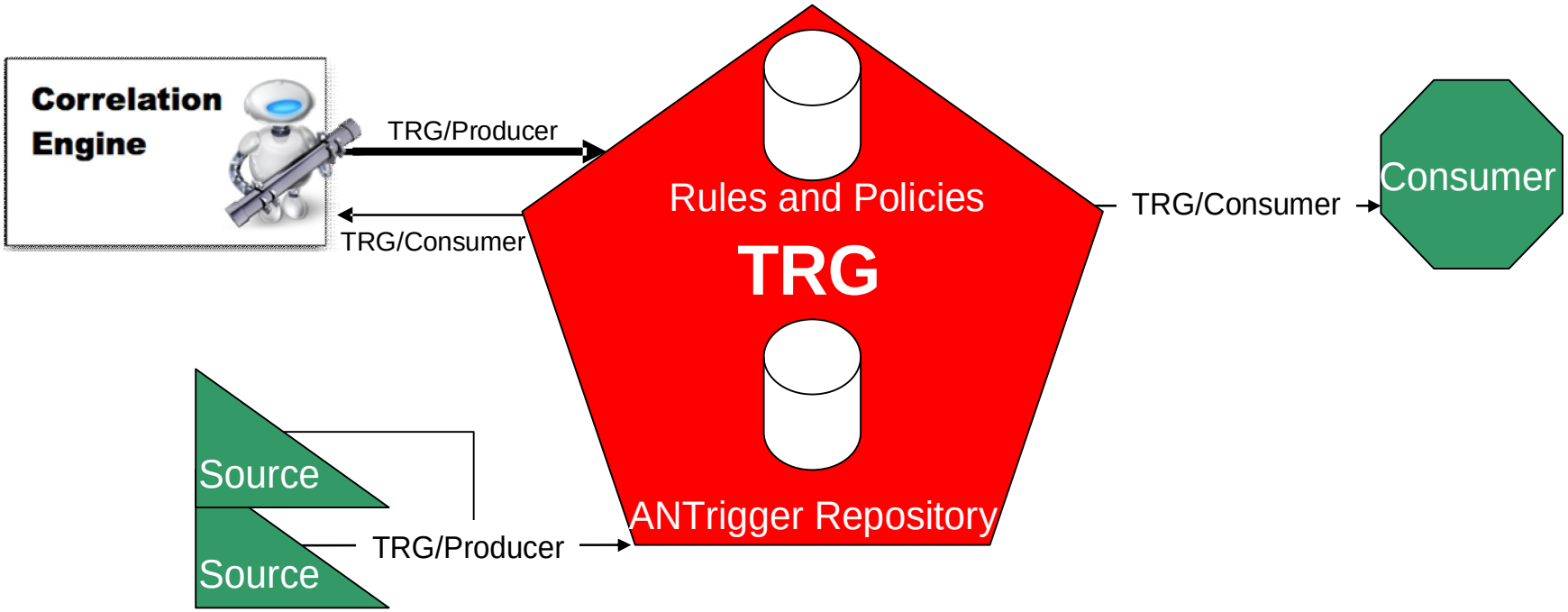
```
chronicle LinkUnstable {
  event(LUD,t1) noevent(LUD,(t1-60,t1-1))
  event(LUD,t2) noevent(LUD,(t1+1,t2-1))
  event(LUD,t3) noevent(LUD,(t2+1,t3-1))
  t1 < t2 < t3
  t3 - t1 < 30
}
```

# Detecting an Unstable Link (10/10)

- Detect the start sequence of, at least, three consecutive “link up/down” triggers within 30s, which is good indication of an unstable link
  - First, define a chronicle for a single link up/down (LUD) event



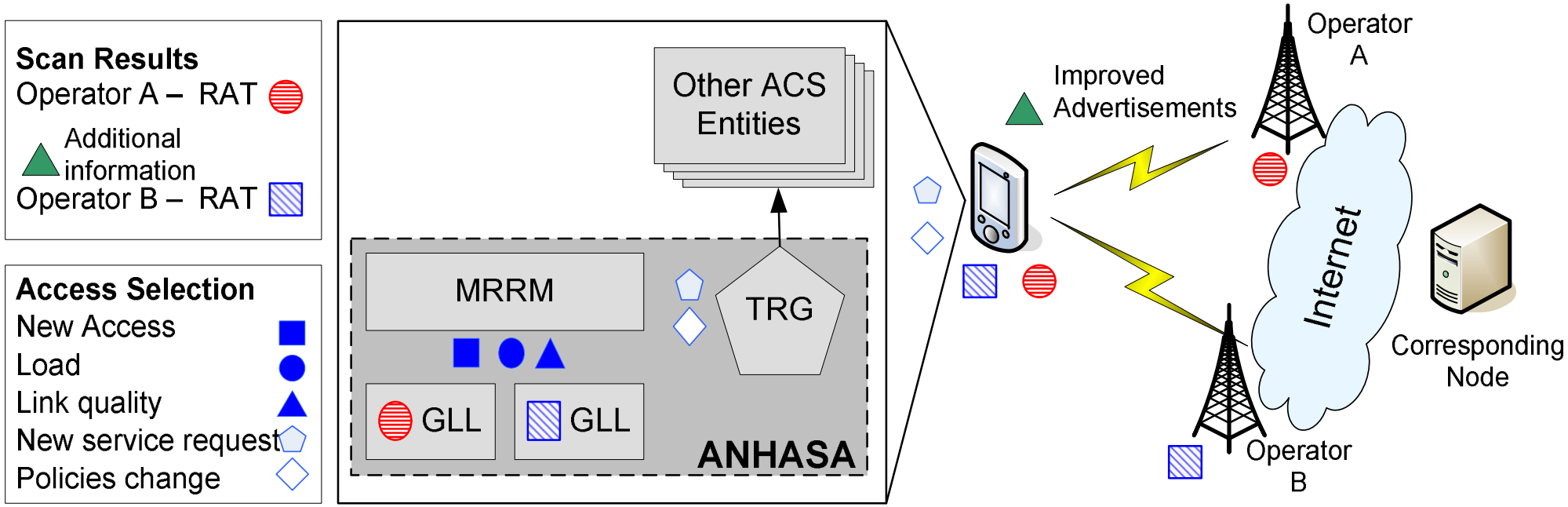
# Trigger Management: The Big Picture Revisited



# The Ambient Networks Heterogeneous Access Selection Architecture

- Access selection in an environment with different overlapping radio technologies
- Ubiquity of multiaccess
  - WLAN, 2.5G/3G/… cellular, WMAN (WiBro, mobile WiMAX)
  - Soon, even low-end devices will come with >3 integrated interfaces
  - Different operators
- Access selection is still rudimentary, not dynamic
  - Relies on presets, static choices and extensive user input
  - Lack of automation
  - Use of policies is limited

# Example Access Selection

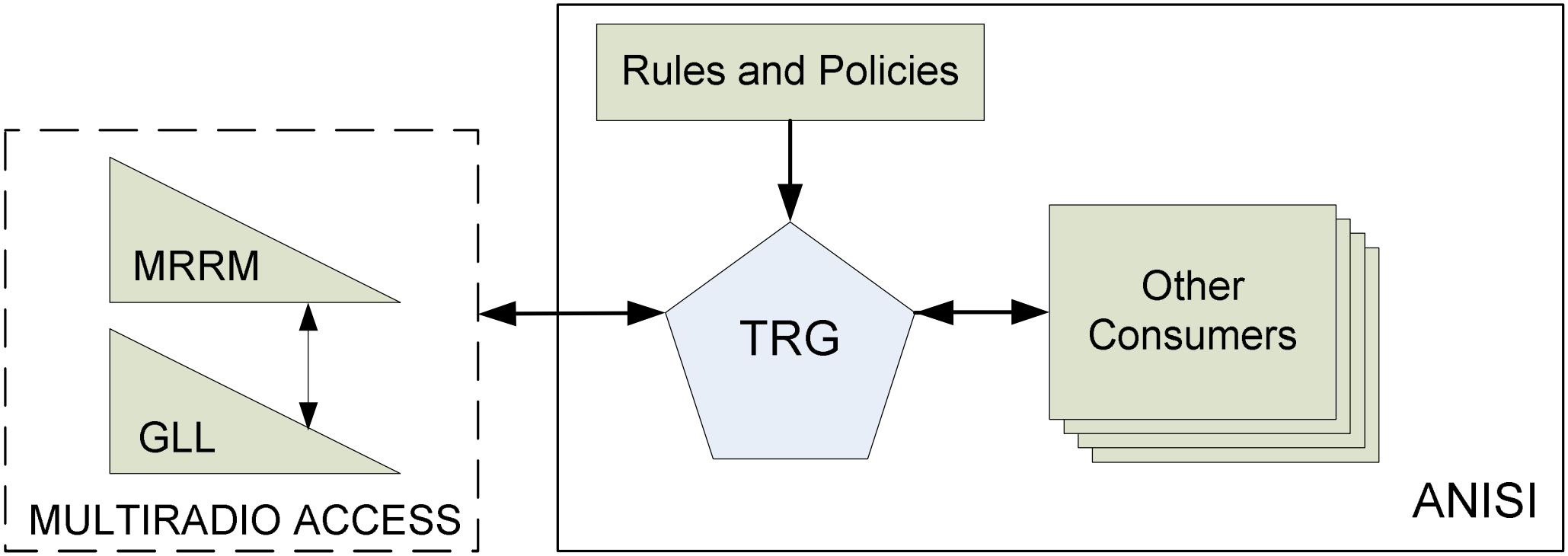



- K. Pentikousis, R. Agüero, J. Gebert, J. A. Galache, O. Blume, P Pääkkönen, “The Ambient Networks heterogeneous access selection architecture”, *Proc. First Ambient Networks Workshop on Mobility, Multiaccess, and Network Management* (M2NM), Sydney, Australia, October 2007, pp. 49–54.

# Drivers and Goals for ANHASA

- Thesis: Future networks will be more heterogeneous than today
  - New networking paradigms (HIP, Post-IP)
  - More mobility management solutions
  - Increasing number of transport protocols
  - Exponential growth in networked applications
- New design for multiaccess nodes, which
  - allows for dynamic use of several networks
  - fosters new solutions for mobility and multiaccess and
  - does not hinder legacy upper layer protocols
  - is modular and incrementally deployable
  - respects the principle of layering

# ANHASA


Rules and Policies
MRRM
GLL
MULTIRADIO ACCESS
TRG
Other
Consumers
ANISI

# ANHASA Components

- Generic Link Layer (GLL)
  - exposes a unified, abstract interface to all available radio accesses
- MultiRadio Resource Management (MRRM)
  - uses GLL measurements and control facilities to direct access selection
- Trigger management (TRG)
  - collects and distributes multiaccess and mobility information relevant to the entire protocol stack
  - registers it with ANISI
- ANISI: AN Information Service Infrastructure

# Generic Link Layer

- The only technology-dependent component of ANHASA
  - Considers implementation-specific variations and details
  - Controls and delivers information
    - from all available radio accesses
    - *and* their associated networks
- ANHASA relies on GLL to
  - abstract access details consistently
  - facilitate a fair comparison between candidates
  - supply a “link quality” metric in the [0, 1] range, which interprets actual link measurements.
    - Also: access network capacity, rate, delay, and load information
  - enable resource optimization and load balancing

# MultiRadio Resource Management

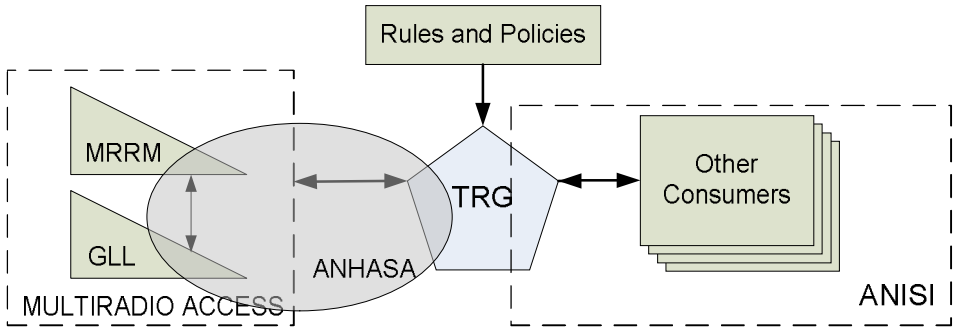
- Directs the advanced joint management of radio resources in heterogeneous access networks
- Performs access selection and load sharing between different radio accesses

# MultiRadio Resource Management

- Provisions neighborhood information
  - Monitors for available access networks
  - Collects link performance and resource consumption information
  - Correlates GLL-provided information with upper layer constraints
- Access selection decisions may lead to a handover execution
  - Use GLL to establish connections to the candidate access(es)
- Implementations can put all functionality at the terminal only, or distribute it into subcomponents located at the terminal (MRRM-TE) and in the access network (MRRM-NET), possibly at different nodes.

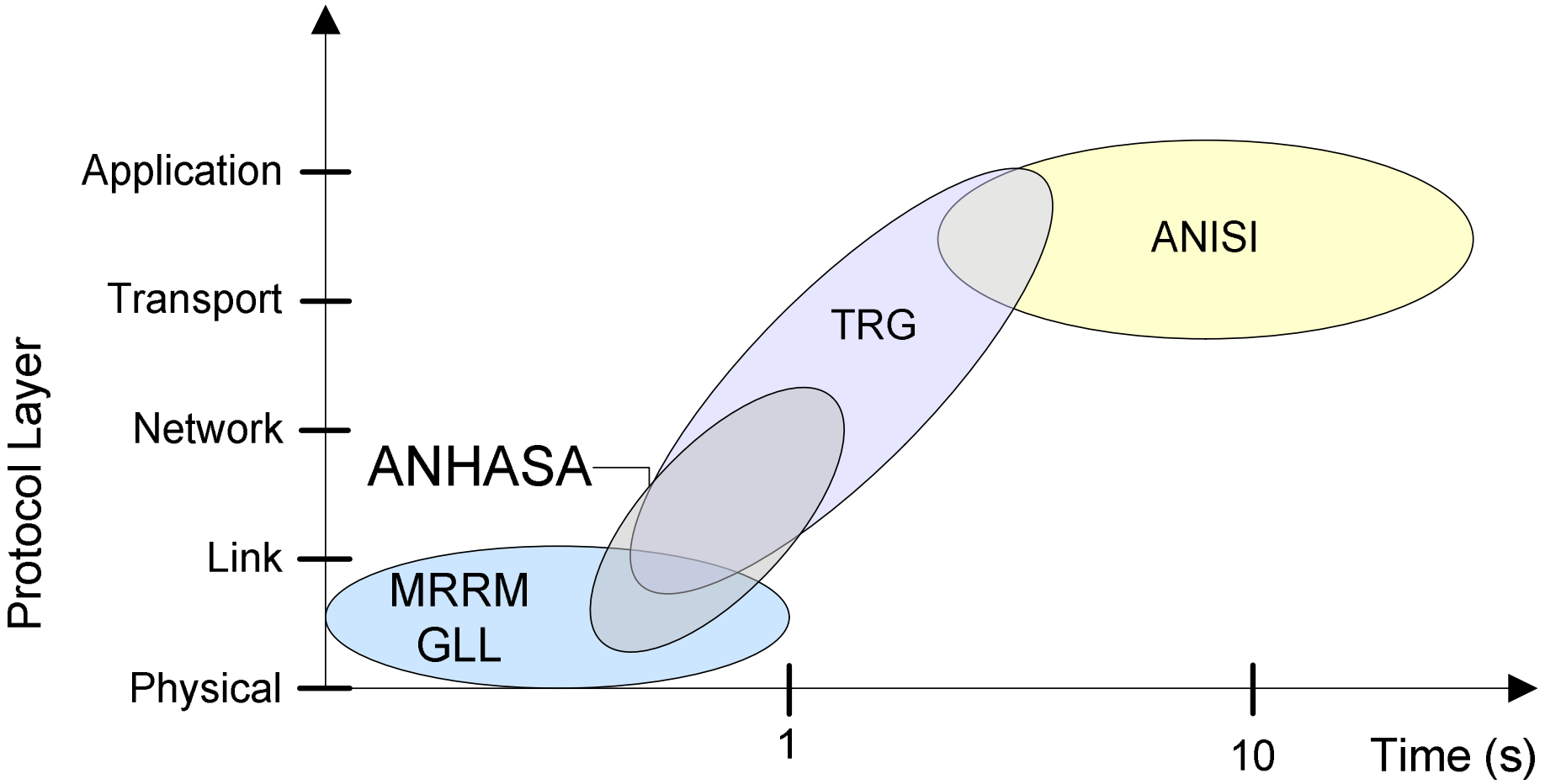
# Trigger Management

- Allows for two-way information sharing throughout the stack
  - Events from the multiaccess component
  - Events from upper layers
  - Applies rules and policies governing management and dissemination
  - Generates standardized notifications (“triggers”)
  - Can generate synthetic triggers based on temporal correlation of events originating from the entire protocol stack




- Essential in making ANHASA modular and extensible

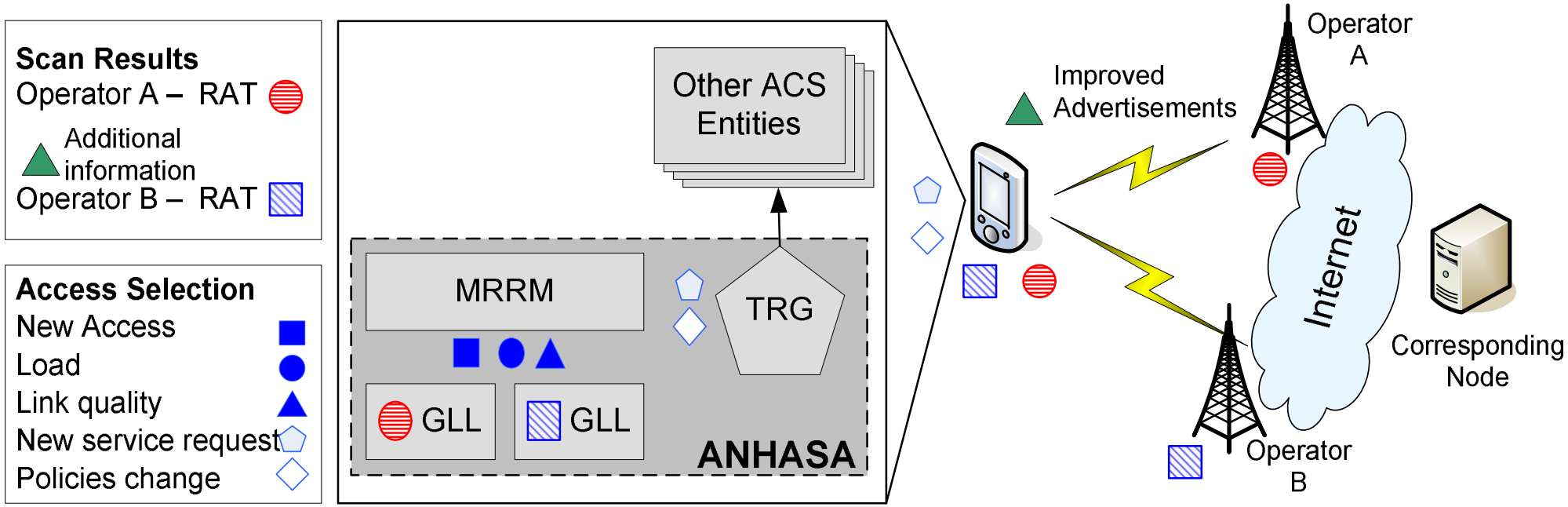
# ANHASA Temporal and Protocol Layer Scope



# ANHASA Operation

1. MRRM configures GLL to report periodically on new access availability
   - Spontaneous requests are welcome J
2. GLL uses link-specific scanning procedures and detects all available networks
3. MRRM
   - gathers information from the entire stack and decides
   - initiates attachment to and detachment from a given access
4. While connected
   - GLL provides abstracted link measurements periodically
   - Select information is shared with the rest of the protocol stack

# Example Access Selection




- K. Pentikousis, R. Agüero, J. Gebert, J. A. Galache, O. Blume, P Pääkkönen, “The Ambient Networks heterogeneous access selection architecture”, *Proc. First Ambient Networks Workshop on Mobility, Multiaccess, and Network Management* (M2NM), Sydney, Australia, October 2007, pp. 49–54.

# ANHASA in a Nutshell

- The Ambient Networks Heterogeneous Access Selection is
  - Inclusive and generic: not a point solution
  - Modular and incrementally deployable
  - Extensible and forward-looking
- Respects the principle of layering
- Considers several parameters
  - Can work well on single- and multi-operator scenarios
- Allows multiaccess, mobility and context information to permeate through the stack

# Tutorial Outline (3/4)

- IEEE 802.21 Media Independent Handover Services
  - Scope and Purpose
  - Example use case
  - Implementation
- Towards Energy-efficient System Designs
- Information Distribution in Dynamic Networks

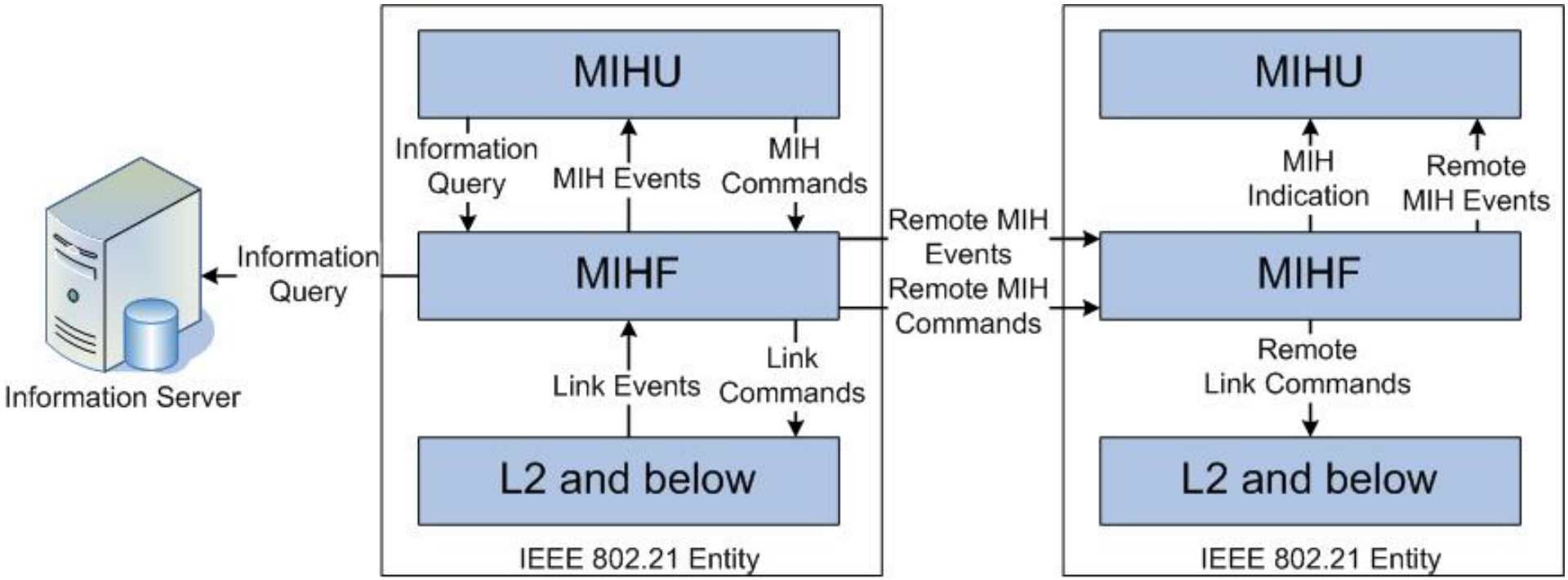
# IEEE 802.21 Scope and Purpose

- Scope—This standard defines extensible IEEE 802 media access independent mechanisms that enable the optimization of handover between heterogeneous IEEE 802 networks and facilitates handover between IEEE 802 networks and cellular networks.
- Purpose—Improve the user experience of mobile devices by facilitating handover between 802 networks whether or not they are of different media types, including both wired and wireless, where handover is not otherwise defined; and to make it possible for mobile devices to perform seamless handover where the network environment supports it. These mechanisms are also usable for handovers between 802 networks and non 802 networks.

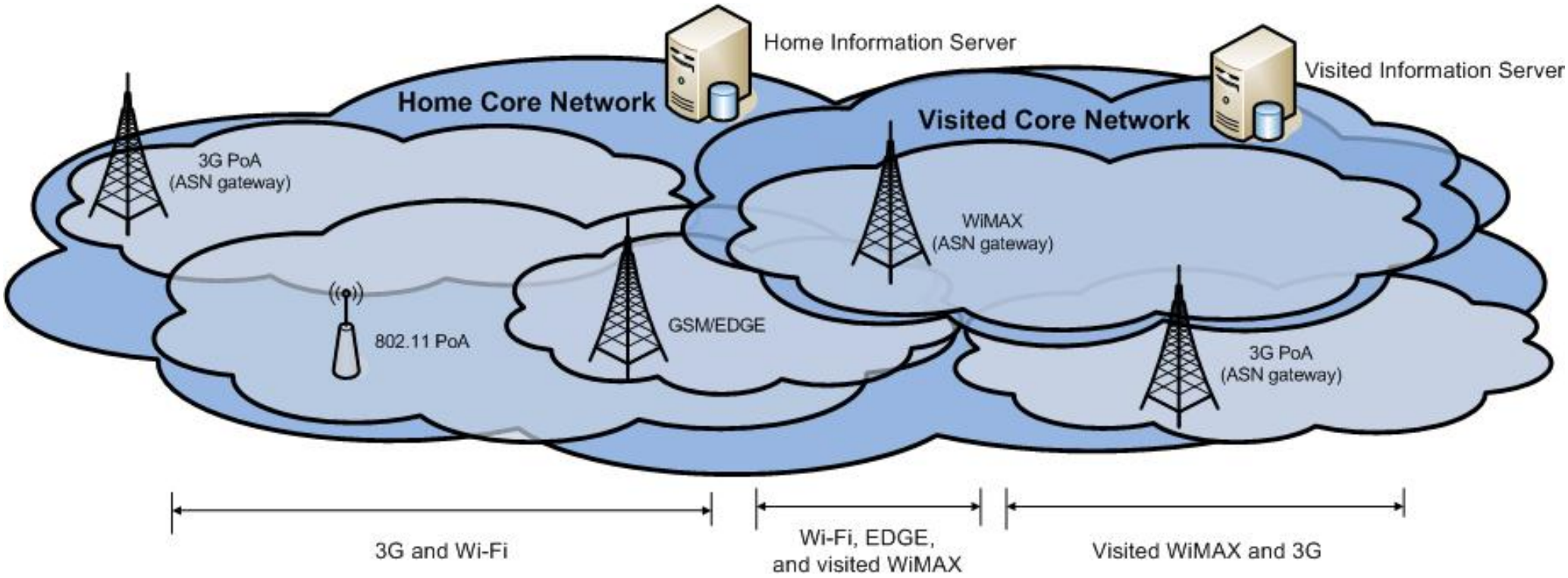
# IEEE 802.21 Timeline

- 2003: Handover Tutorial
- 2004: IEEE 802.21 WG created
- 2005: Initial Draft Standard
- 2006-2007: Letter Ballot
- 2008: Sponsor Ballot
- 2008-11: Standard Accepted
- 2009-1: Standard Published

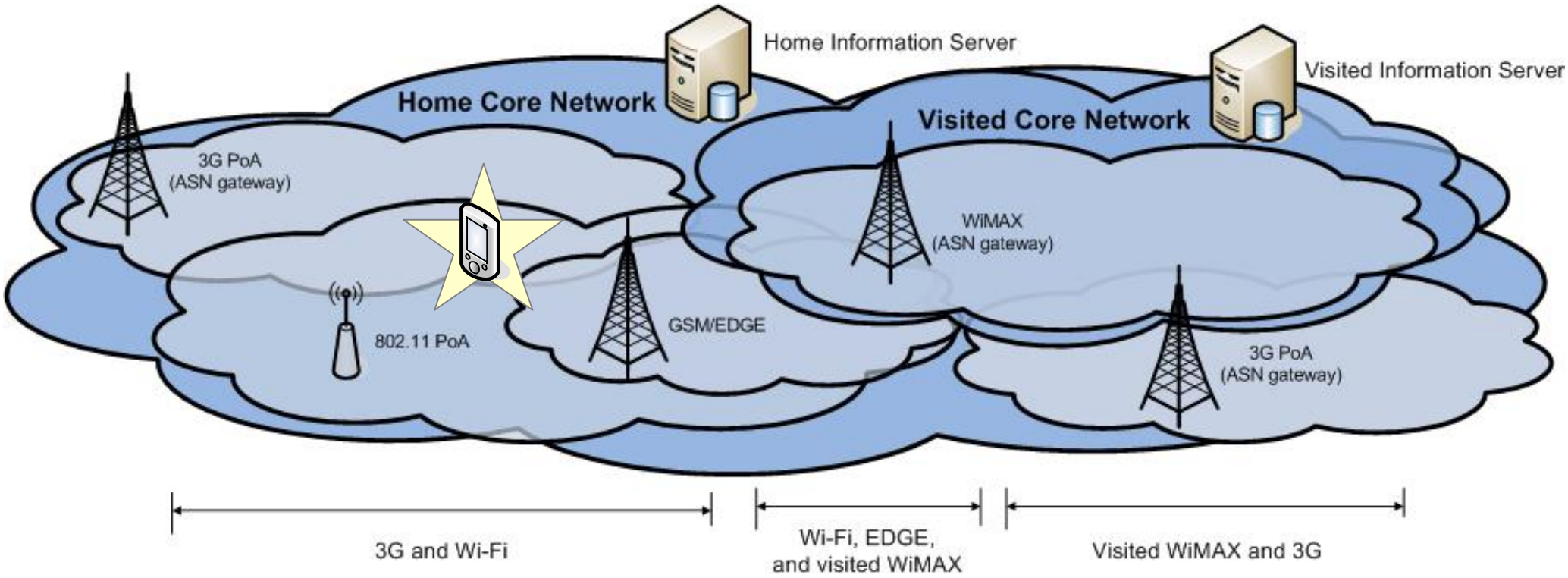
# Media Independent Handover Services



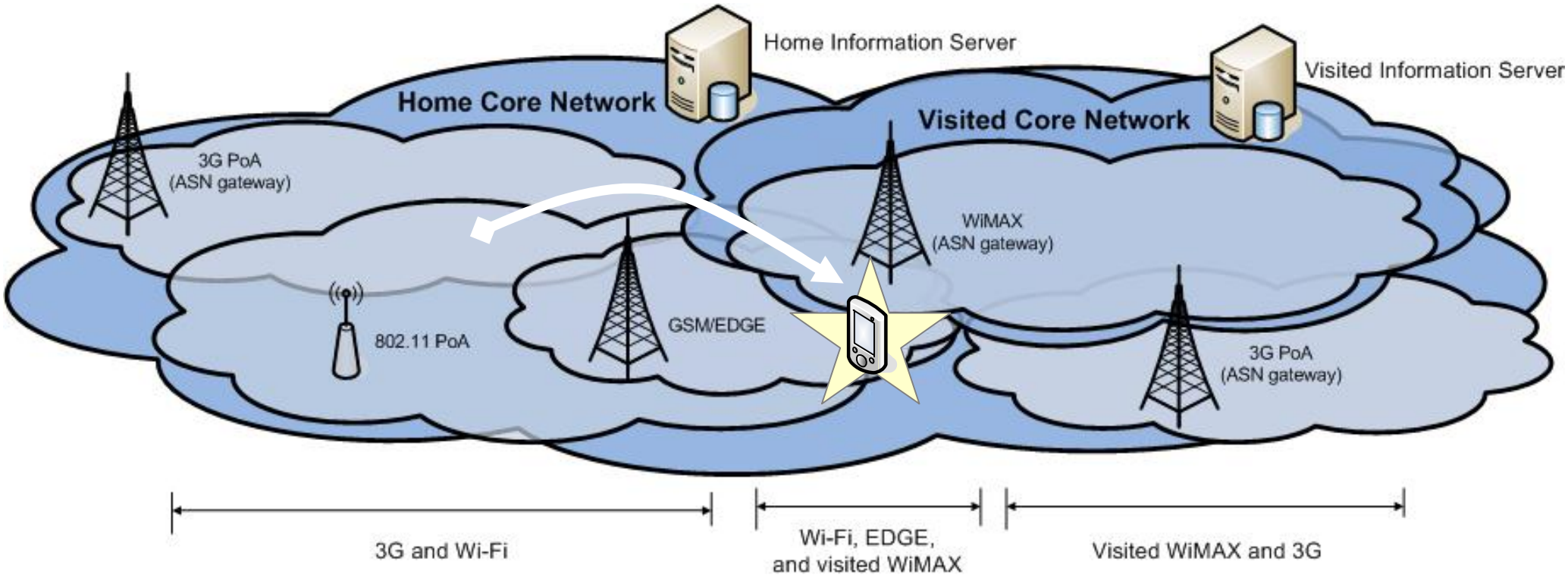
# Example: heterogeneous overlapping wireless networks



# Phase I


Home Information Server
Visited Information Server
Home Core Network
Visited Core Network
3G PoA
(ASN gateway)
WiMAX
(ASN gateway)
802.11 PoA
GSM/EDGE
3G PoA
(ASN gateway)
3G and Wi-Fi
Wi-Fi, EDGE,
and visited WiMAX
Visited WiMAX and 3G

# Phase II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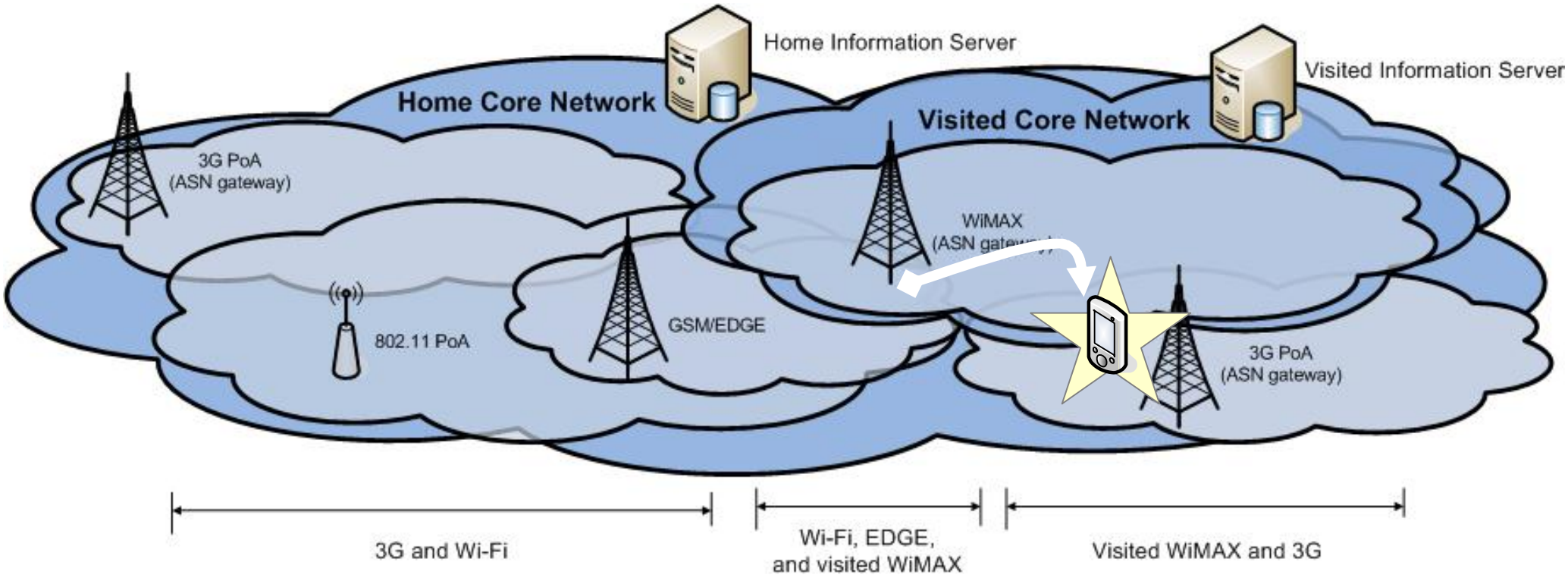
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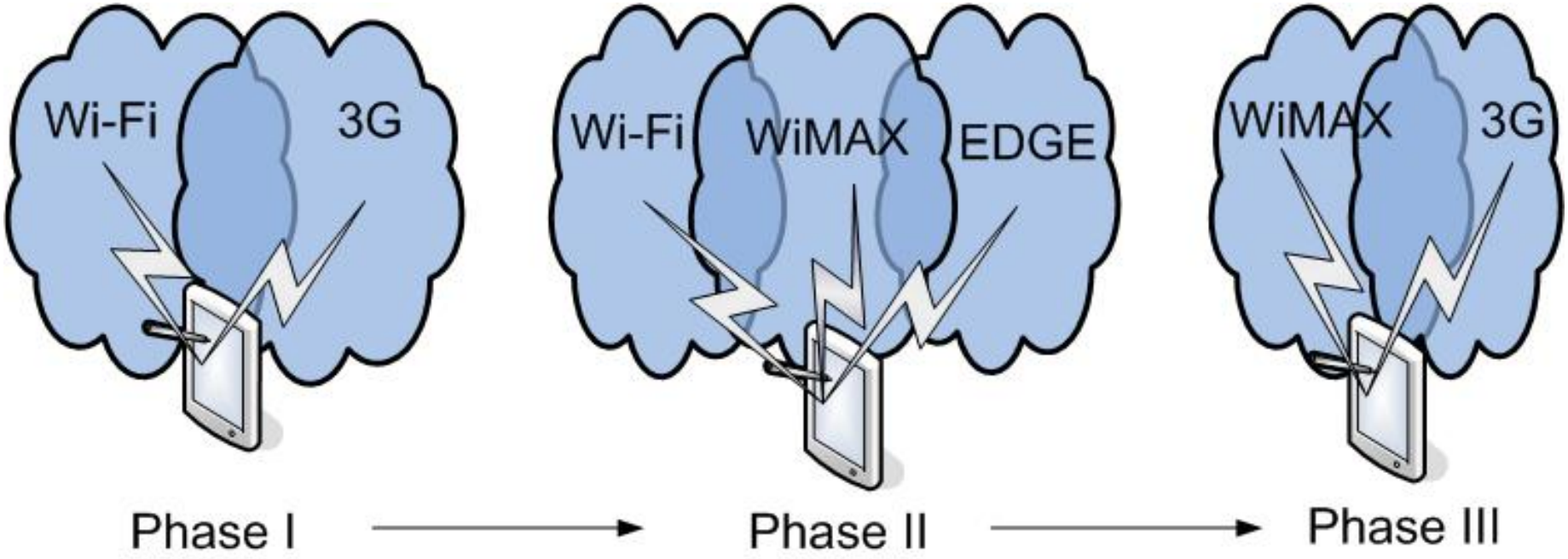
# Summary: heterogeneous overlapping wireless networks



# IEEE 802.21: Out of Scope

- Intra-technology handover (except for handovers across extended service sets (ESSs) in case of IEEE 802.11)
- Handover policy
- Security mechanisms
- Enhancements specific to particular link layer technologies that are required to support this standard; they will be carried out by those respective link-layer technology standards
- Higher layer (layer 3 and above) enhancements that are required to support this standard.

# Further Reading

- *IEEE Standard for Local and Metropolitan Area Networks. Part 21: Media Independent Handover Services*. IEEE Std 802.21-2008, January 2009
- E. Piri and K. Pentikousis, “IEEE 802.21: Media Independent Handover Services”, *The Internet Protocol Journal*. To appear.

# IEEE 802.21 MIHF Implementation

- *Work in progress*
  - Tremendous experience with TRG a big plus
  - The draft standard is often a moving target
  - Integration with stock MIPv6 and HIP planned
  - Extensions for TCP, monitoring points, H.264/SVC using MIIS
- Minimal version for GNU/Linux working in the lab already:
  - E. Piri and K. Pentikousis, “Towards a GNU/Linux IEEE 802.21 implementation”, *Proc. IEEE ICC 2009 Communications Software and Services Symposium* (ICC), Dresden, Germany, June 2009.

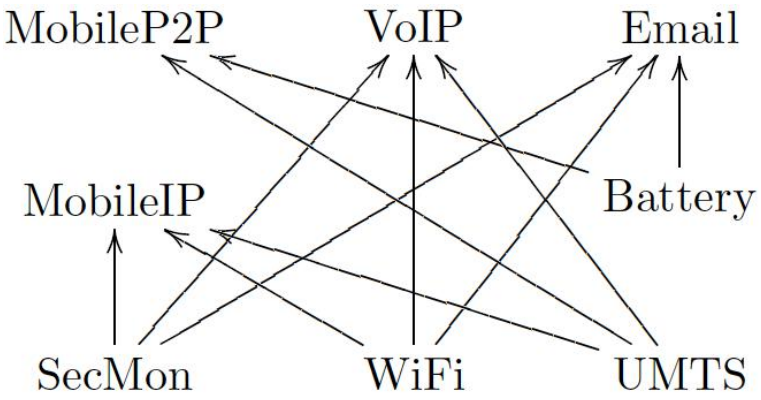
# 2009: IEEE 802.21 Becomes the Next Big Thing, Then?

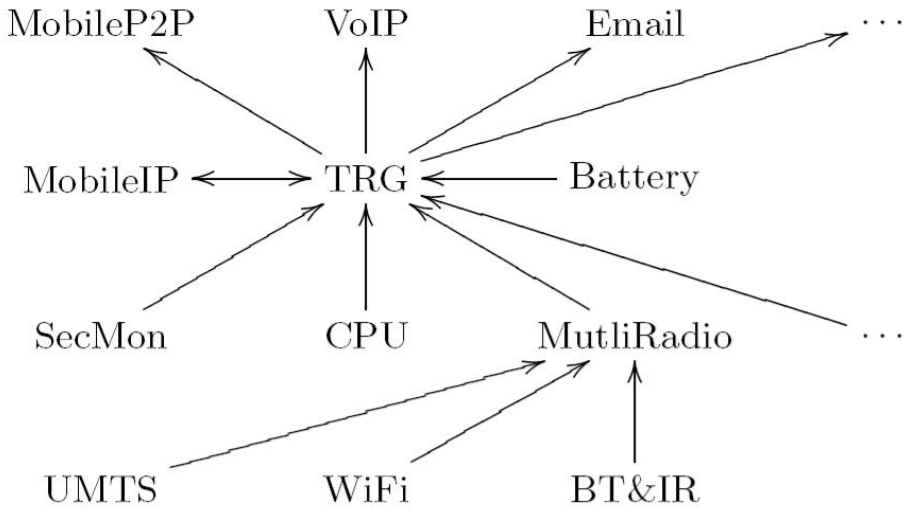
- Are we oblivious to some new stuff out there?
  - The same way the Mobile IP folks missed the cellular deployment
- Are we blind to something that will change the world fundamentally in the coming 10 years?
- Or, are the next ten years going to be devoted to enhancements of IEEE 802.21-2008?

- Will get back to you at ICN 2019 J

# Towards Energy-efficient System Designs

- Trigger management can serve as the foundation for new energy-efficient system designs

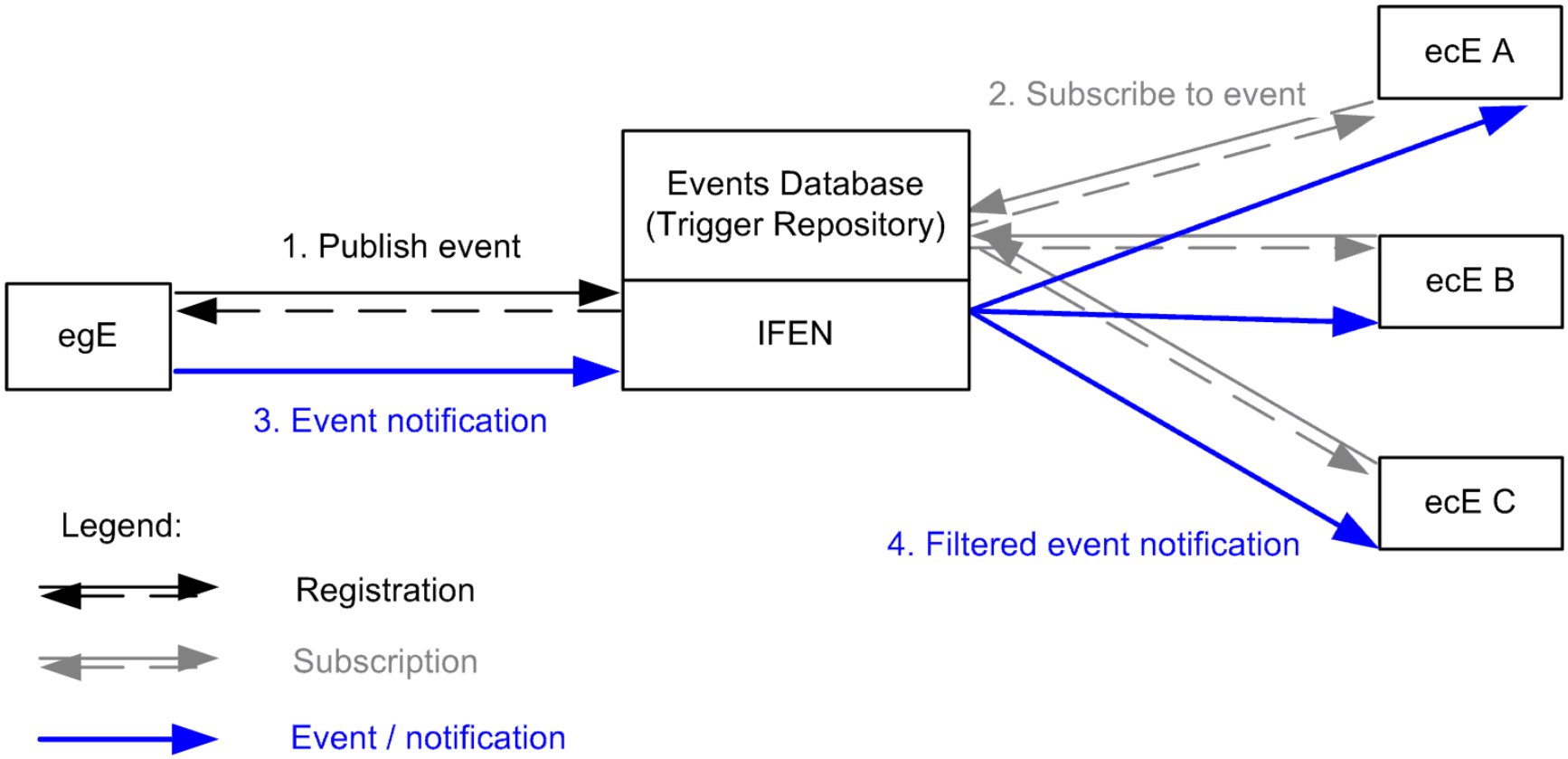


# Information Distribution in Dynamic Networks

- Unprecedented dynamicity in forthcoming networks
- Need for self-X properties becomes prevalent
  - Self-configuration, self-optimization, self-adaptation, self-management, and self-healing, just to name a few…
  - In the Ambient Networks context, composition also an important driver
  - Collaboration and cooperation frameworks emerge
- Current solutions for self-X:
  - IETF MANET routing protocols: broadcast + active polling
  - IETF NEMO: mobile router and (mobility-agnostic) nodes
  - IETF MIPSHOP: capitalize on IEEE 802.21, but recall: static IEs
  - DNS, DHCP,…
- Need a generic toolbox for event/notification distribution to enable self-X

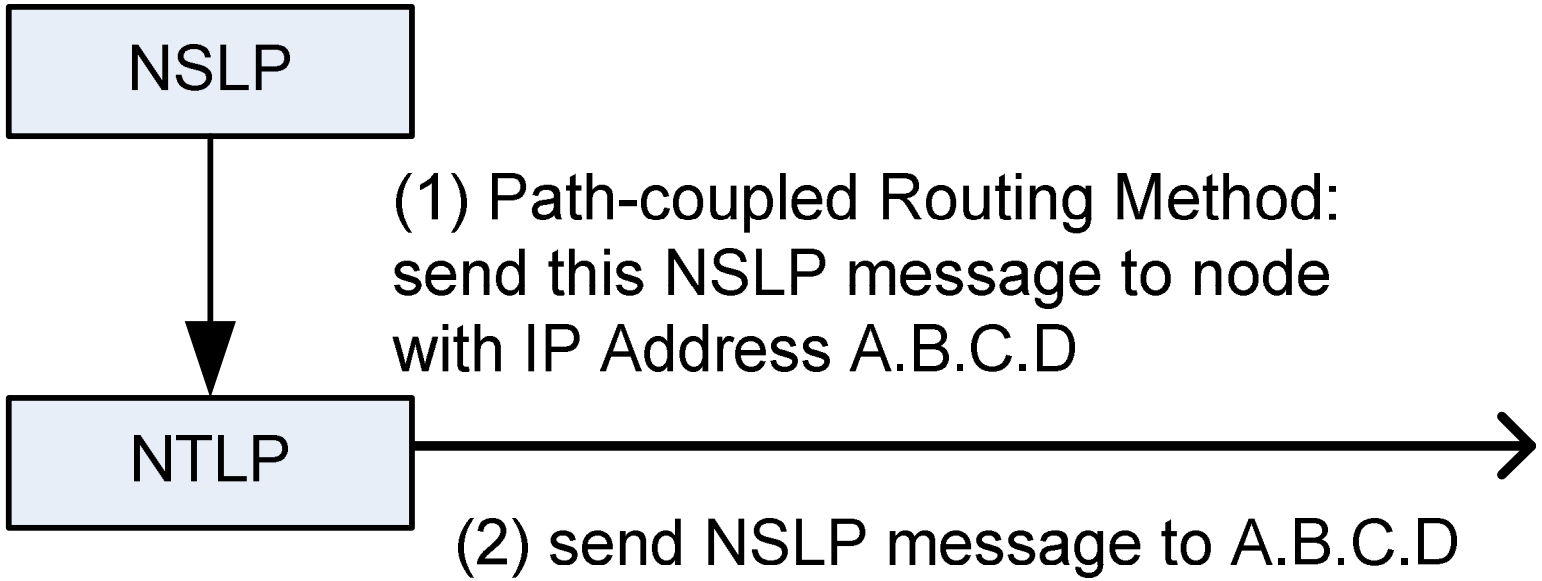
# Inter-function Event and Notification



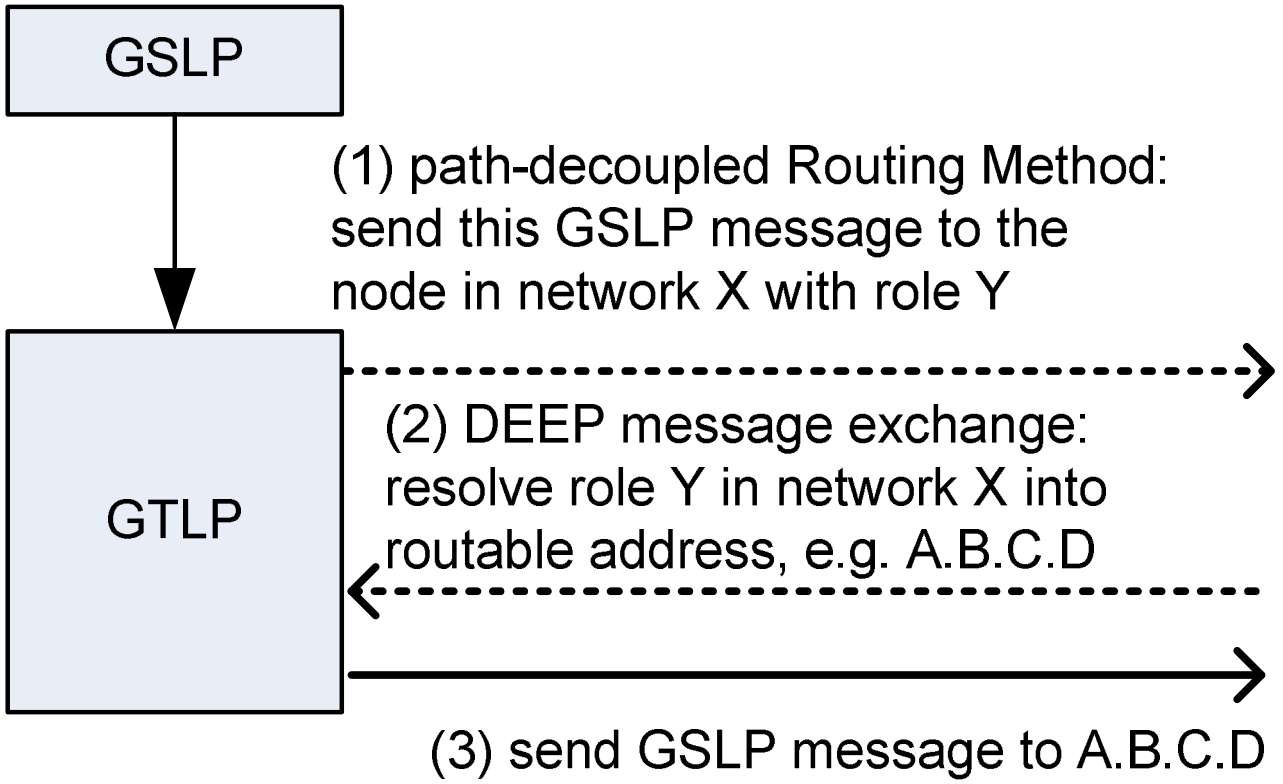
# Event-based Addressing

- In dynamic environments, the event generating entity does not know the role, the identity or the routable addresses of the event consuming entities
- The event-generating entity might not even know which entities may be interested in consuming the events it can generate
- We extend the addressing scheme of GANS to include event-based addressing
- In technical terms, we add a new Routing Method, the event-based Routing Method

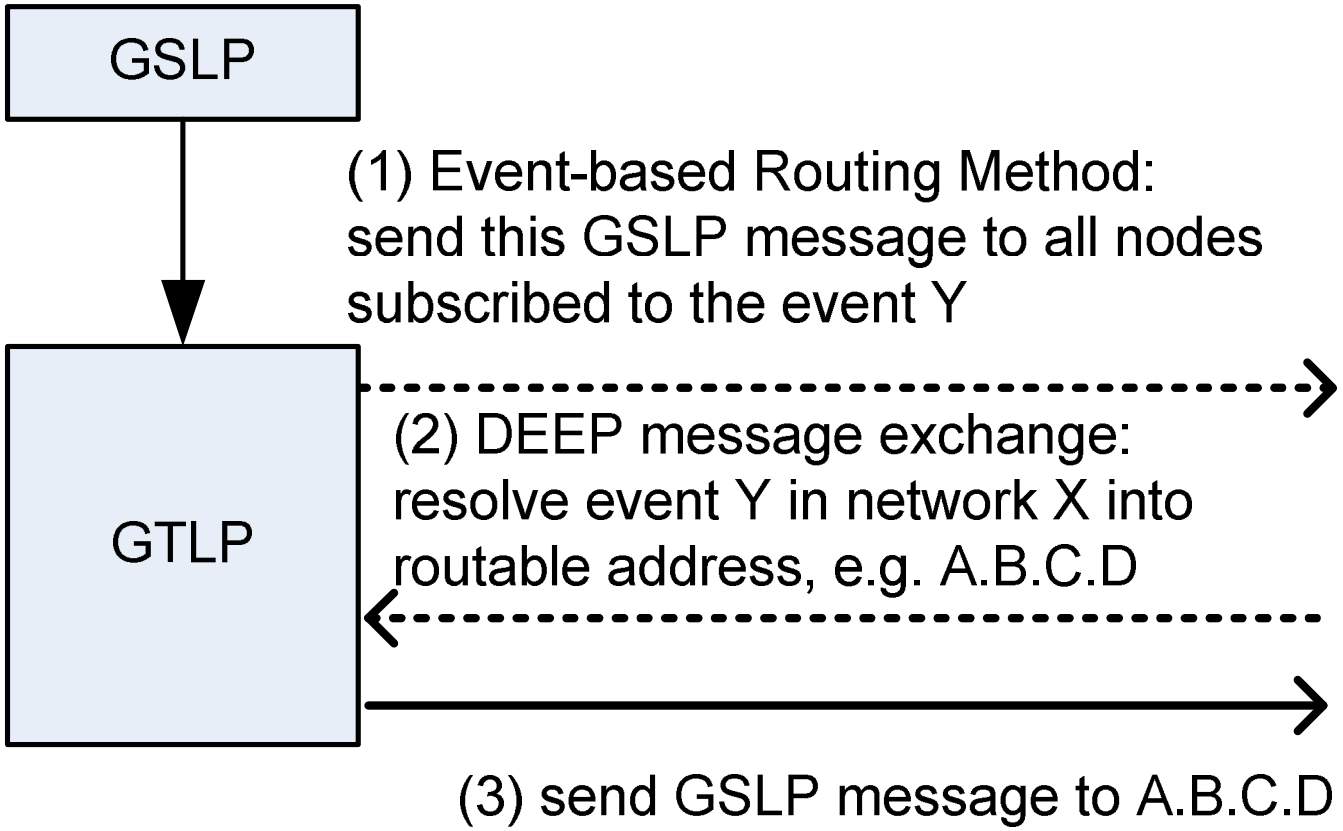
# From NSIS …


NSLP
(1) Path-coupled Routing Method:
send this NSLP message to node
with IP Address A.B.C.D
NTLP
(2) send NSLP message to A.B.C.D

# … to Generic Ambient Network Signaling (GANS) …



# … to Event-Based Addressing (EBA)



# Further Reading


- R. Hancock, G. Karagiannis, J. Loughney, and S. Van den Bosch, Next Steps in Signaling (NSIS): Framework, IETF RFC 4080, June 2005.
- N. Akhtar, R. Campos, C. Kappler, P. Pääkkönen, P.Pöyhönen, and D. Zhou, “GANS: a signalling framework for dynamic interworking between heterogeneous networks”, *Proc. IEEE VTC Fall 2006*, Montreal, Canada, September 2006.
- P. Pöyhönen, N. Akhtar, R. Campos, C. Kappler, P. Pääkkönen, and D. Zhou, “DEEP - A generic name resolution protocol for heterogeneous networks”, *Proc. Second IEEE ICCTA 2006*, Damaskus, Syria, April 2006.
- C. Kappler, K. Pentikousis, and C. Pinho, “Event-based addressing for information distribution in dynamic networks”, *Proc. IEEE 67th Vehicular Technology Conference* (VTC2008-Spring), Marina Bay, Singapore, May 2008, pp. 2849 - 2853.
- C. Pinho, J. Ruela, K. Pentikousis, and C. Kappler, “A protocol for event distribution in next-generation dynamic networks”, *Proc. Fourth EURO-NGI Conference on Next Generation Internet Networks* (NGI), Krakow, Poland, April 2008, pp. 123-130.

# Tutorial Outline (4/4)

- The Changing Nature of Multiaccess
- Content Delivery in a Mobile Wireless World
- 4WARD
  - Architecture and Design for the Future Internet
- Towards information-centric networking

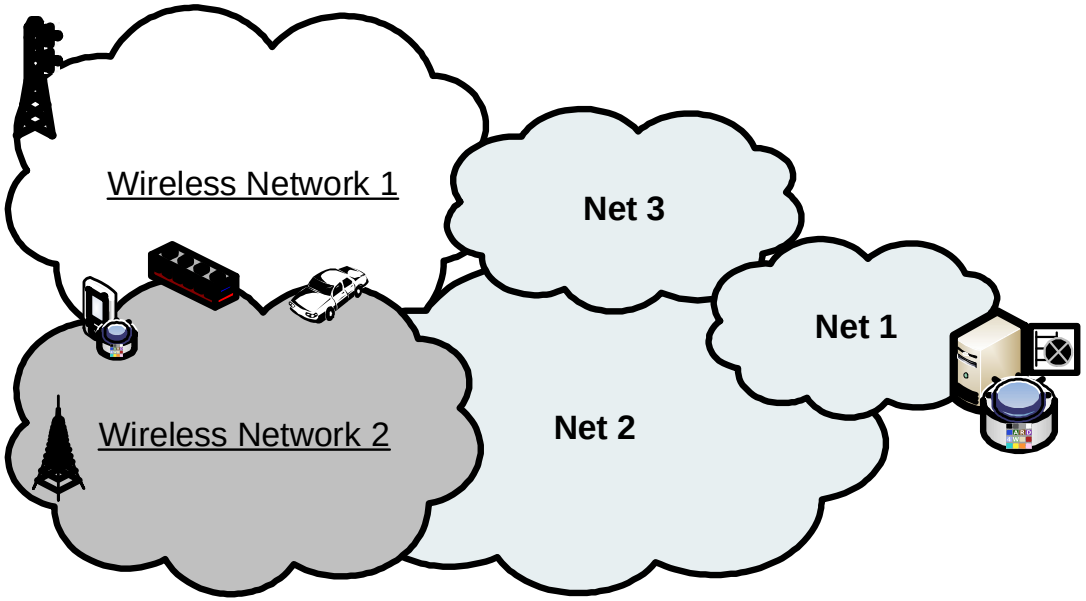
# The Changing Nature of Multiaccess

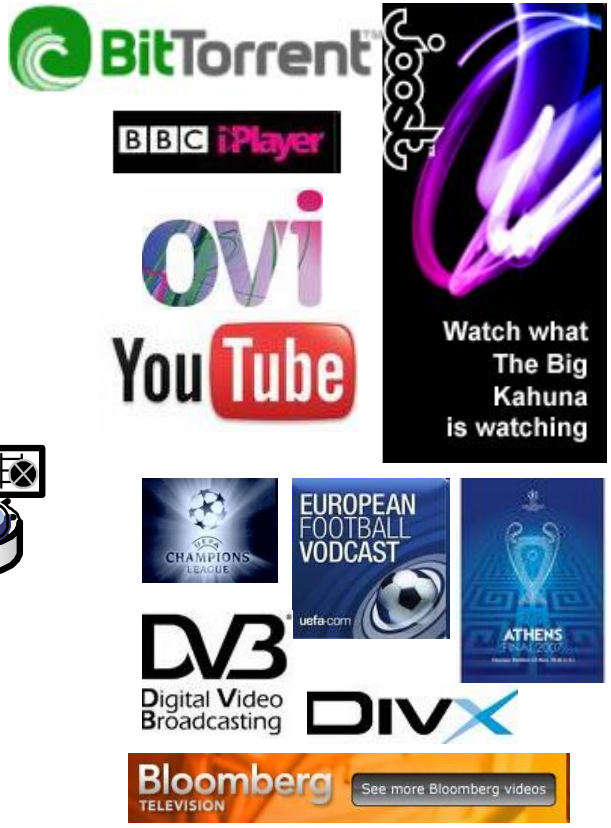
- In ABC each type of network has a special purpose
  - Cellular (global reachability)
  - WLAN (increased capacity, lower cost)
  - Fixed (high capacity, flat rate?)
- But, this may no longer be the case
  - Proliferation of different radio accesses
  - Despite 3GPP domination, new things pop up
    - City-wide WLANs
    - Wi-Fi confederations
    - WiMAX
  - Battery consumption...
  - Multiaccess paging

# PowerBook G3 *vs.* Nokia N95

| | **G3 (1997)** | **N95 (2007)** |
|---|---|---|
| Primary Memory (MB) | 32 | 160 |
| CPU | G3 250 MHz | ARM v11 333 MHz |
| Secondary storage (GB) | 5 + CDROM | … 8 (MicroSDHC) |
| Networking | 10Base-T Ethernet | GSM, GPRS, EDGE, WCDMA, HSDPA<br>Bluetooth, IrDA<br>IEEE 802.11 b/g |

# Content Delivery in a Mobile Wireless World




Many available networks

# Further Reading

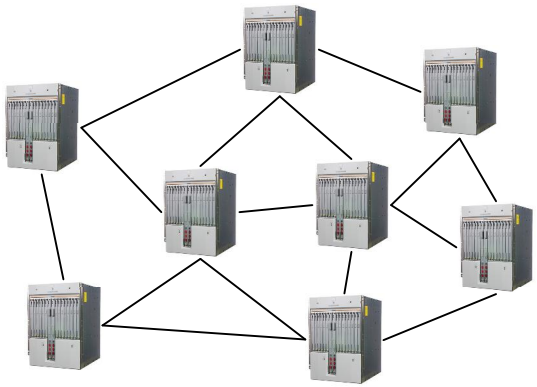

- H. Tang, P. Pöyhönen, O. Strandberg, K. Pentikousis, J. Sachs, F. Meago, J. Tuononen, and R. Agüero, “Paging issues and methods for multiaccess”, *Proc. International Conference on Communications and Networking in China* (CHINACOM), Shanghai, China, August 2007, pp. 769-776.
- C. Dannewitz, K. Pentikousis, R. Rembarz, E. Renault, O. Strandberg, J. Ubillos, “Scenarios and Research Issues for a Network of Information”, *Proc. Fourth International Mobile Multimedia Communications Conference* (MobiMedia), Oulu, Finland, July 2008.
- M. Söllner, C. Görg, K. Pentikousis, J. M. Cabero Lopez, M. Ponce de Leon, and P. Bertin, “Mobility scenarios for the Future Internet: The 4WARD approach”, *Proc. 11th International Symposium on Wireless Personal Multimedia Communications* (WPMC), Saariselkä, Finland, September 2008.

# Third Generation Redux

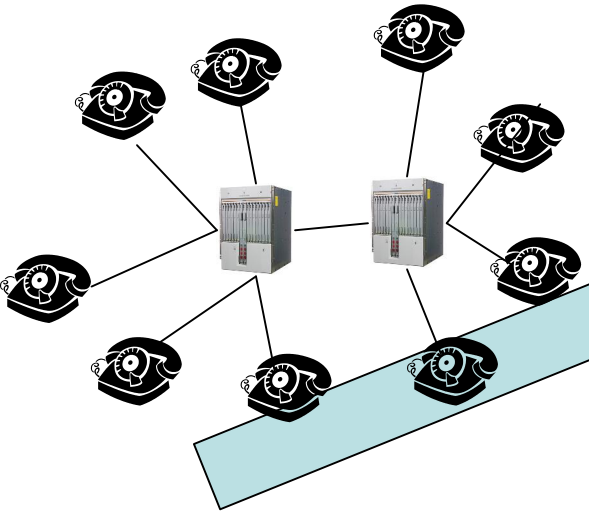
- Jacobson *et al.* argue for the need to transition into the third generation of networking.
  - V. Jacobson, M. Mosko, D. Smetters, and J. Garcia-Luna-Aceves. Content-centric networking. Whitepaper, Palo Alto Research Center, Jan. 2007.
  - The first generation dealt with connecting wires and laying down infrastructure.
  - The second one placed end nodes, instead of the interconnecting points, at the forefront, leading to the emergence of the WWW and widespread Internet adoption.
  - The third generation will refocus the point of attention to what humans care the most about: information.


# 4WARD
# Future Internet
Interconnecting *information*

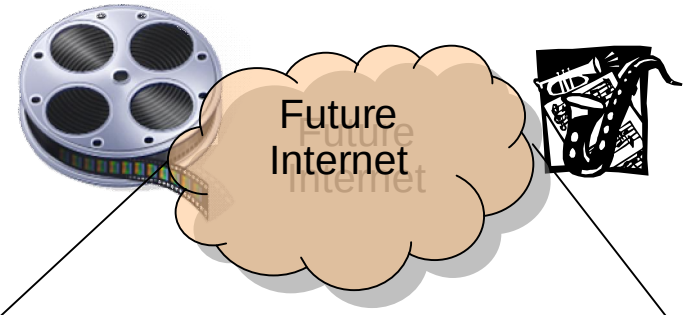
## Internet
Interconnecting *nodes*

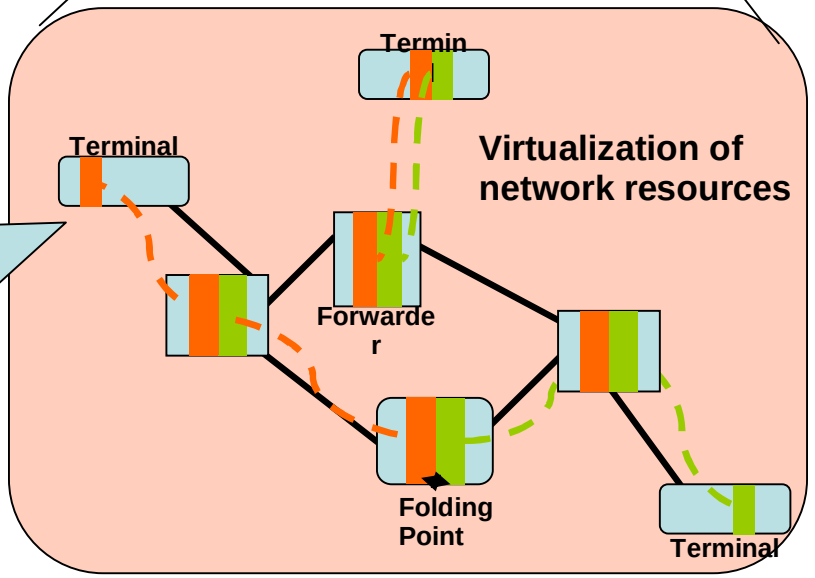


## Telephony
Interconnecting *wires*



Evolution

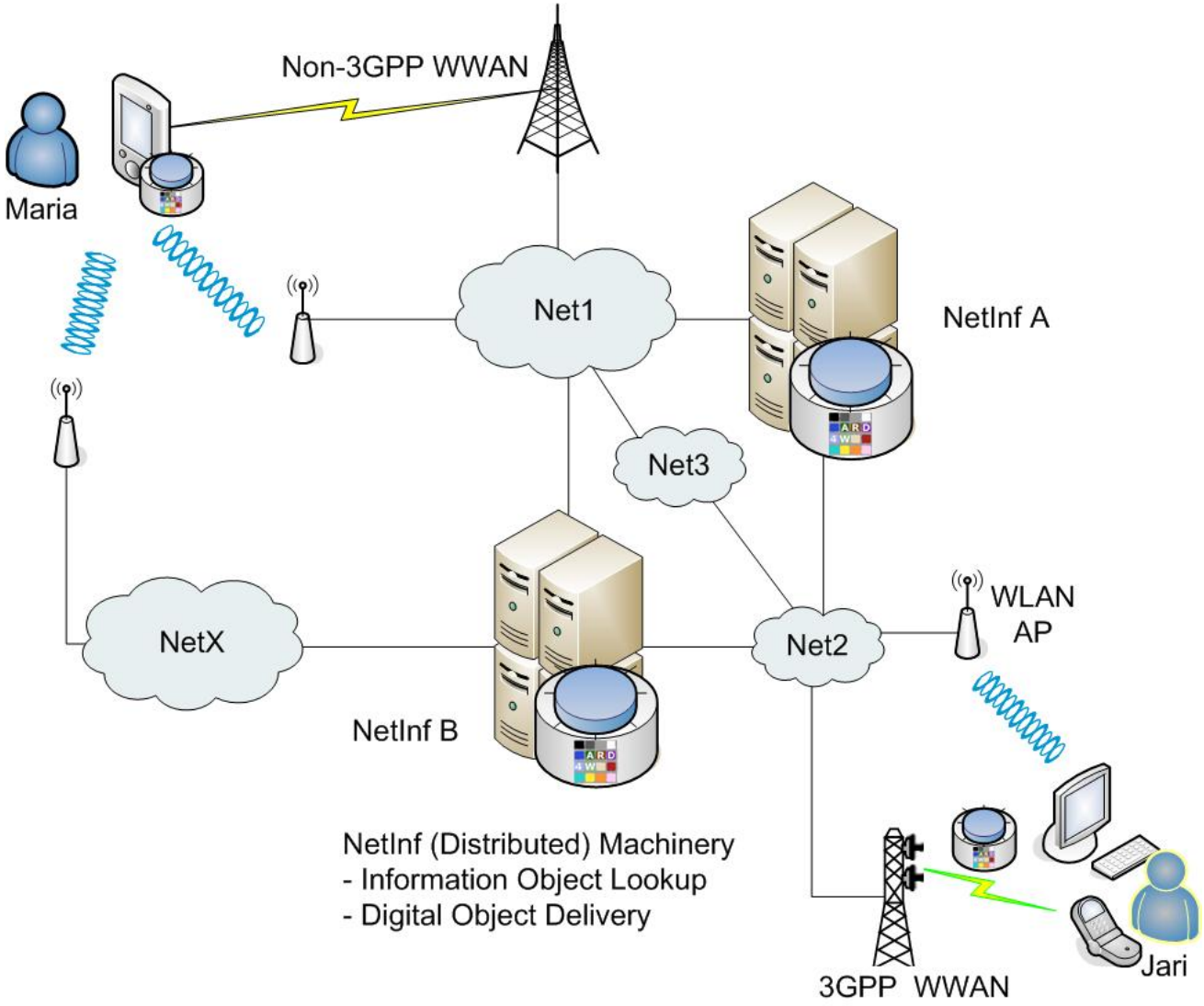


# A Multiaccess Communication Scenario

- The scenario applies to dissemination and non-dissemination objects
  - Dissemination is defined not on an encoding or protocol basis
  - Web, Internet radio/TV, RSS, and so on, are dissemination objects
  - Internet banking, VoIP call, mailbox are non-dissemination objects
- Scenario (and topology figure) covers
  - Web, BitTorrent, A/V streaming, VoIP, ...
  - Communication with a multiaccess/multiapplication device (Maria)
  - Communication with a user having multiple devices (Jari)

# A Multiaccess Communication Scenario



# Further Reading


- B. Ahlgren, M. D'Ambrosio, C. Dannewitz, M. Marchisio, I. Marsh, B. Ohlman, K. Pentikousis, R. Rembarz, O. Strandberg, and V. Vercellone, "Design considerations for a Network of Information", *Proc. ReArch'08 - Re-Architecting the Internet Workshop*, Madrid, Spain, December 2008.
- K. Pentikousis, F. Fitzek, and O. Mammela, "Cooperative multiaccess for wireless metropolitan area networks: An information-centric approach", *Proc. IEEE Workshop on Cooperative Mobile Networks* (CoCoNet), collocated with IEEE ICC 2009, Dresden, Germany, June 2009. To appear

# Web Sites

- www.ambient-networks.org
- www.ist-weird.eu
- www.4ward-project.eu
- www.future-internet.fi

# Acknowledgements


- Part of this work has been carried out in the framework of
  - Ambient Networks (FP6 IST-027662)
  - WEIRD (FP6 IST-034622)
  - 4WARD (FP7 grant agreement no. 216041)

  which were partially funded by the Commission of the European Union.
- The views expressed do not necessarily represent the views of VTT, the respective projects, or the Commission of the European Union.

# Thank You!