# Information-Centric Networking & the Ψ Architecture


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# Outline

- Introduction, motivation, overview
- An Overlay Approach
- The PSI (clean-slate) Architecture
- Discussion & Conclusion

# Internet Clean-Slate Design

- What stood at the beginning
  - Collaboration
  - Cooperation
  - NO commercial traffic allowed!
- Endpoint-centric services not enough
- What about:
  - Trust?
  - Legitimacy of E2E?
    - NAT, firewalls, middleboxes
  - Role of overlays?
  - Information centrism?

**Clean-slate design…**

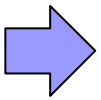
- Question ALL fundamentals
- Challenge our thinking
- Take nothing for granted, including industry structures
- Clear vision

**…with late binding (to reality)**

- Consider migration and evolvability in separate work items
  - How to get our design into real deployments, e.g., overlay vs. IP replacement?
- Consider necessary evolution of industry (and regulatory) structures
  - How do industries need to evolve in certain scenarios?

# Motivation for an Information-Oriented Architecture

- **End-to-end** communication **is not** the prevailing paradigm
  - Firewalls, NATs, proxy-servers…
  - **Information-centric use** of the Internet (e.g. CDNs, proxy-servers)
  - Overlay content delivery structures ignore
    - network topology & data location
    - Request aggregation hard to achieve without information-awareness!
- Imbalance of power in favor of the sender
  - The network will forward anything a sender will inject
- No trust
  - E.g., phishing, spam, viruses, worms, etc.
- No adequate support for mobility (& multicast)



It's the new ways the Internet is used, for which it was not designed…

# Relevant Research Projects

- **PSIRP**: Publish Subscribe Internet Routing Paradigm
  - FP7 ICT STREP, 2008-2010
  - **the basis**


- **PURSUIT**: Publish Subscribe Internet Technologies
  - FP7 ICT STREP, 2010-2013
  - revisiting, extending, above and below the Internet layer


- **Euro-NF**: Anticipating the Network of the Future—From Theory to Design
  - FP7 ICT NoE, 2008-2011+
  - various topics, including network architecture


- **EIFFEL**: FP7 ICT SSA, 2008-2010
  - Think-Tank continues
    - next meeting in June-July 2011 at MIT

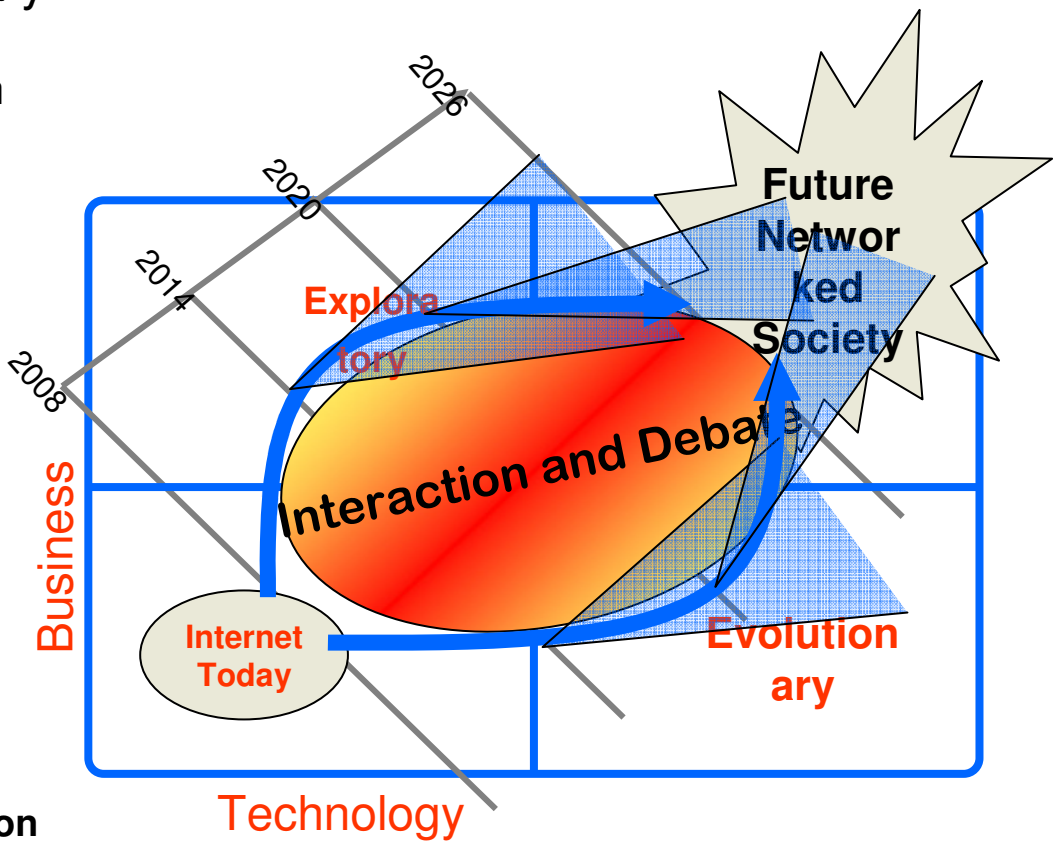
# **EIFFEL**: Evolved Internet Future For European Leadership (FP7 SSA)

- Recognize importance of evolutionary & explorative path (**balance**)
- Vision trajectories developed for both paths (**research agendas**)
- Development of agendas over time (**phased approach**)

**Interaction & debate needed for agendas & visions meet in common challenge**

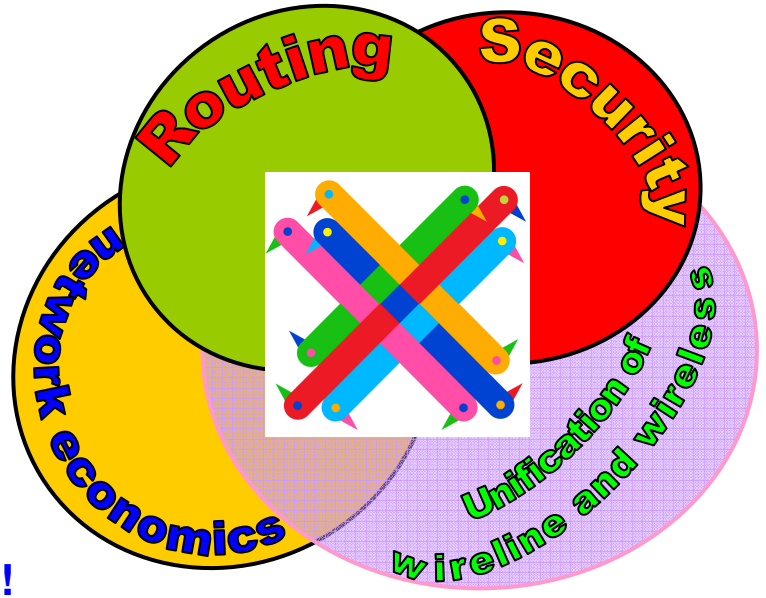
- **Think Tank meetings**
- **White Papers**
- **FIpedia**

- **Creation of a community of scientific & technical experts**
- **Creation of European Dialog**
- **Identification of the areas of investigation and research that are crucial for the transformation of the Internet towards the Future Networked Society**



# Publish Subscribe Internet Routing Paradigm (PSIRP) Vision

- Envision a system that dynamically adapts to evolving concerns and needs of its participating users
  - **information centrism**
- Publish–subscribe based internetworking architecture restores the balance of network economics **incentives between the sender and the receiver**
- Recursive use of publish-subscribe paradigm enables dynamic change of roles between actors




**Objectives**

- Specify, implement and test an internetworked pub/sub architecture
  - follow a **clean-slate design** approach
- Perform qualitative and quantitative evaluation
  - **Security and socio-economics important!**
  - Migration and incentive scenarios important (e.g., overlay)!

# The PSIRP Project

- EU FP7 ICT STREP, 2008-2010 (http://www.psirp.org/)

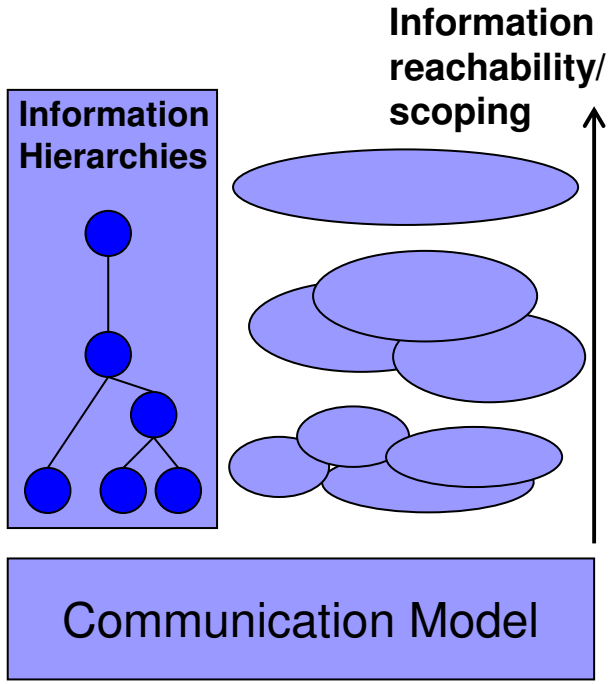
- A Pub/Sub based clean-slate architecture for the Future Internet
- Multicast (& caching) will be the norm
- Security (& privacy) are main design goals
- Mobility will be considered from the early stages of the design

- *Everything* is **Information**… (content, meta-data, publications…)
- Trust-to-Trust (T2T) principle

  - Helsinki Institute for Information Technology (HIIT)
  - RWTH Aachen
  - British Telecom (BT)
  - Oy LM Ericsson Ab (LMF)
  - Nokia Siemens Networks Oy (NSNF)
  - Athens University of Economics and Business (AUEB)
  - Institute for Parallel Processing, Bulgarian Academy of Science (IPP-BAS)
  - Ericsson Hungary Ltd. (ETH)

# Main Design Principles of the Ψ Architecture

- Information is multi-hierarchically organised
  - Higher-level information semantics are constructed in the form of directed acyclic graphs (DAGs), starting with meaningless forwarding labels towards higher level concepts (e.g., ontologies).
- Information scoping
  - Mechanisms are provided that allow for limiting the reachability of information to the parties having access to the particular mechanism that implements the scoping.
- Scoped information neutrality
  - Within each scope of information, data is only forwarded based on the given (scoped) identifier.
- The architecture is receiver-driven
  - No entity shall be delivered data unless it has agreed to receive those beforehand, through appropriate signalling methods.



# An Information-Centric Overlay Network Architecture for Content Distribution and Mobility Support

Ph.D. Dissertation by Konstantinos Katsaros

- **Multicast**
  - *Router Assisted Overlay Multicast (RAOM)*
    - Deploying multicast functionality in an overlay fashion
- **Multicast & Caching**
  - *MultiCache*
    - Enabling caching of data delivered by multicast trees
- **Adapting to the inter-network structure**
  - *H-Pastry*
    - Canonical version of Pastry
- **Mobility Support**
  - *Overlay Multicast Assisted Mobility (OMAM)*
    - Revisiting multicast assisted mobility

K.V. Katsaros, G. Xylomenos, and G.C. Polyzos, "**MultiCache: an Overlay Architecture for Information-Centric Networking**," ***Computer Networks***, vol. 55, no. 4, pp. 936-947, Elsevier, Special Issue on 'Architectures and Protocols for the Future Internet,'March 2011.

N. Fotiou, K.V. Katsaros G.C. Polyzos, M. Särelä, D. Trossen, G. Xylomenos, "**Handling Mobility in Future Publish-Subscribe Information-Centric Networks**," ***Telecommunication Systems***, Springer, Special Issue on 'Mobility Management in the Future Internet,' to appear.

# The PSI (Pub/Sub Internet) Architecture

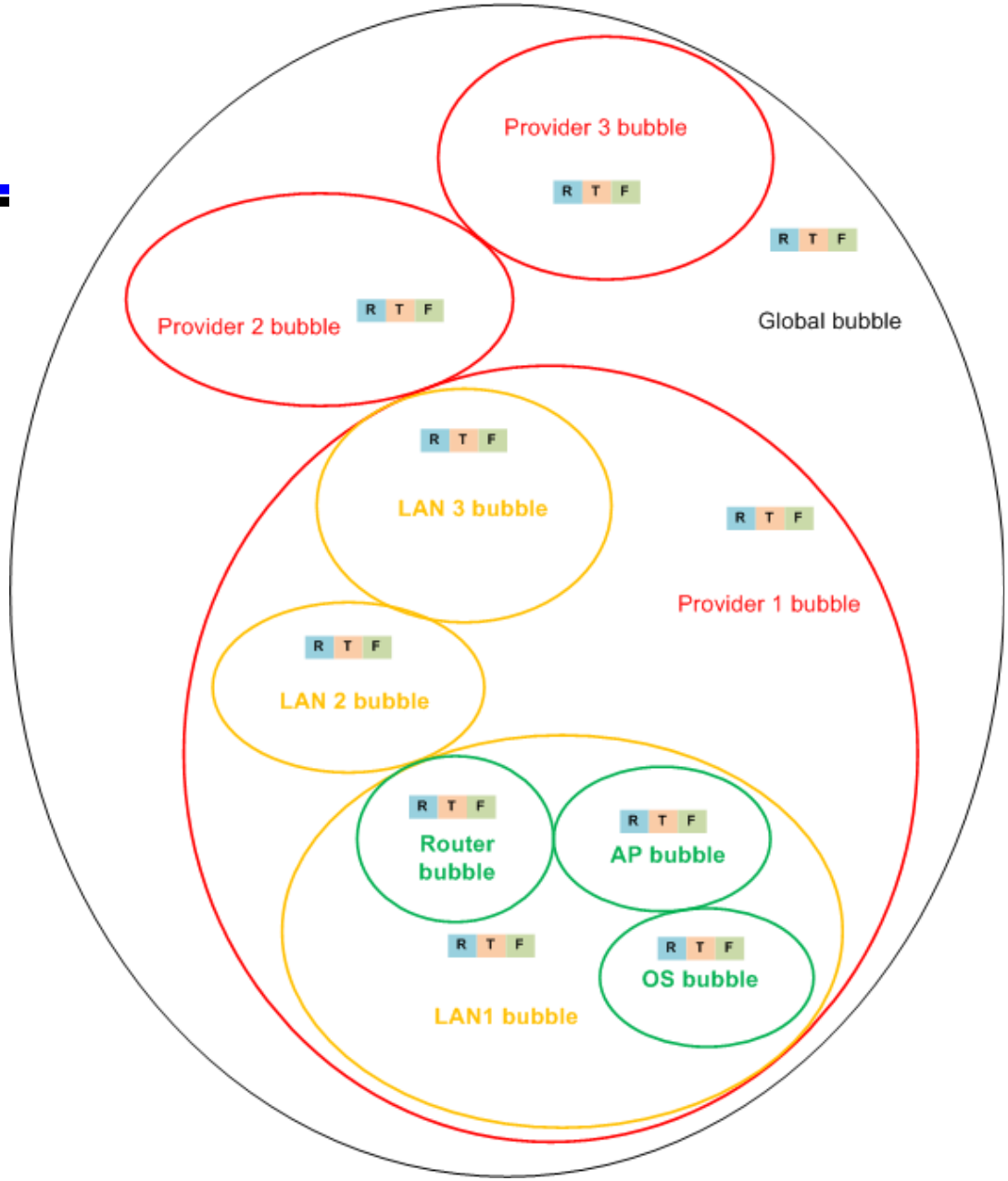
- Ψ

- Clean-Slate
- Native

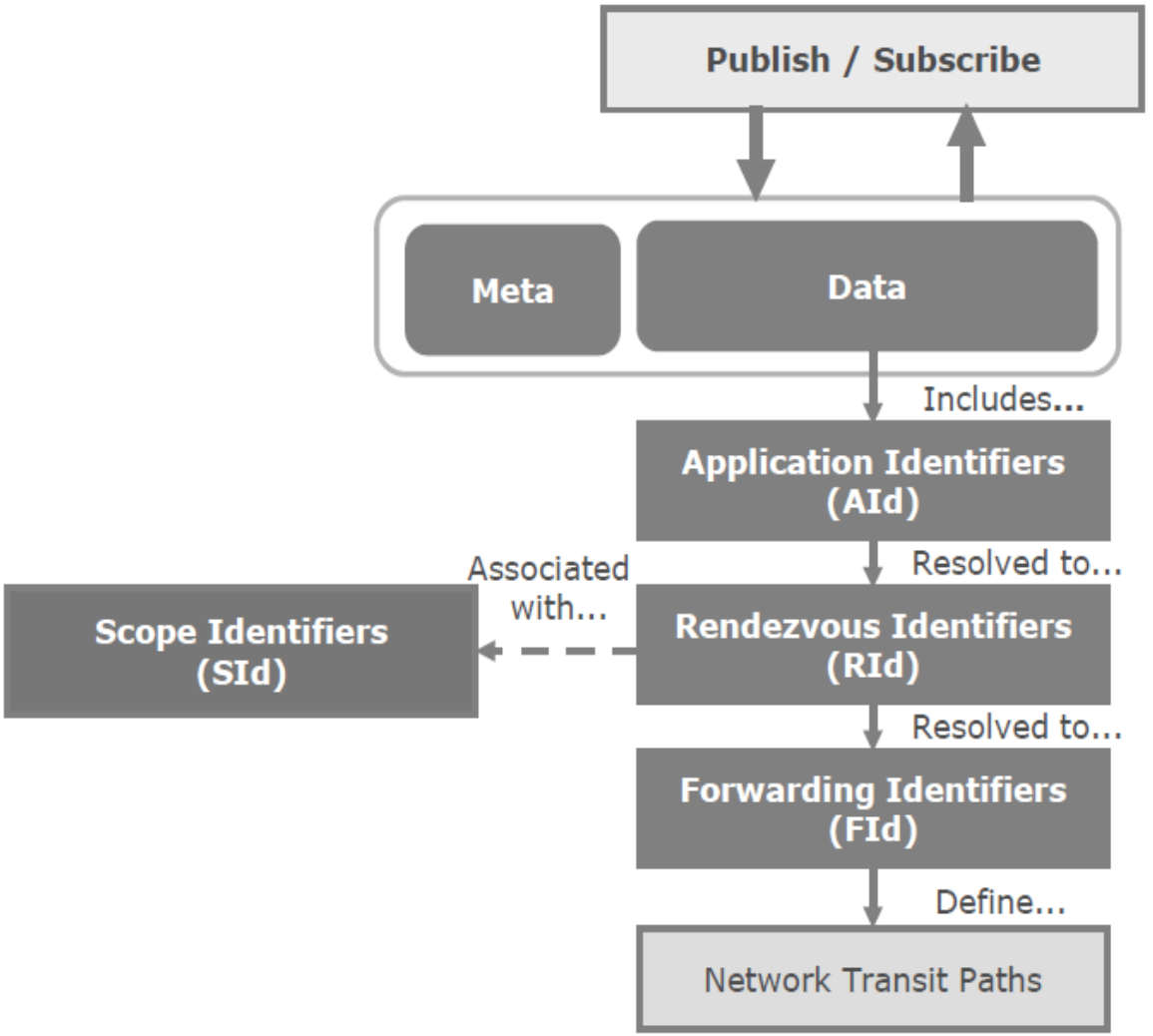
- Two different prototype implementations exist
  - Blackhawk (PSIRP)
  - Blackadder (PURSUIT)
- More coming up...?

# Basic Functions

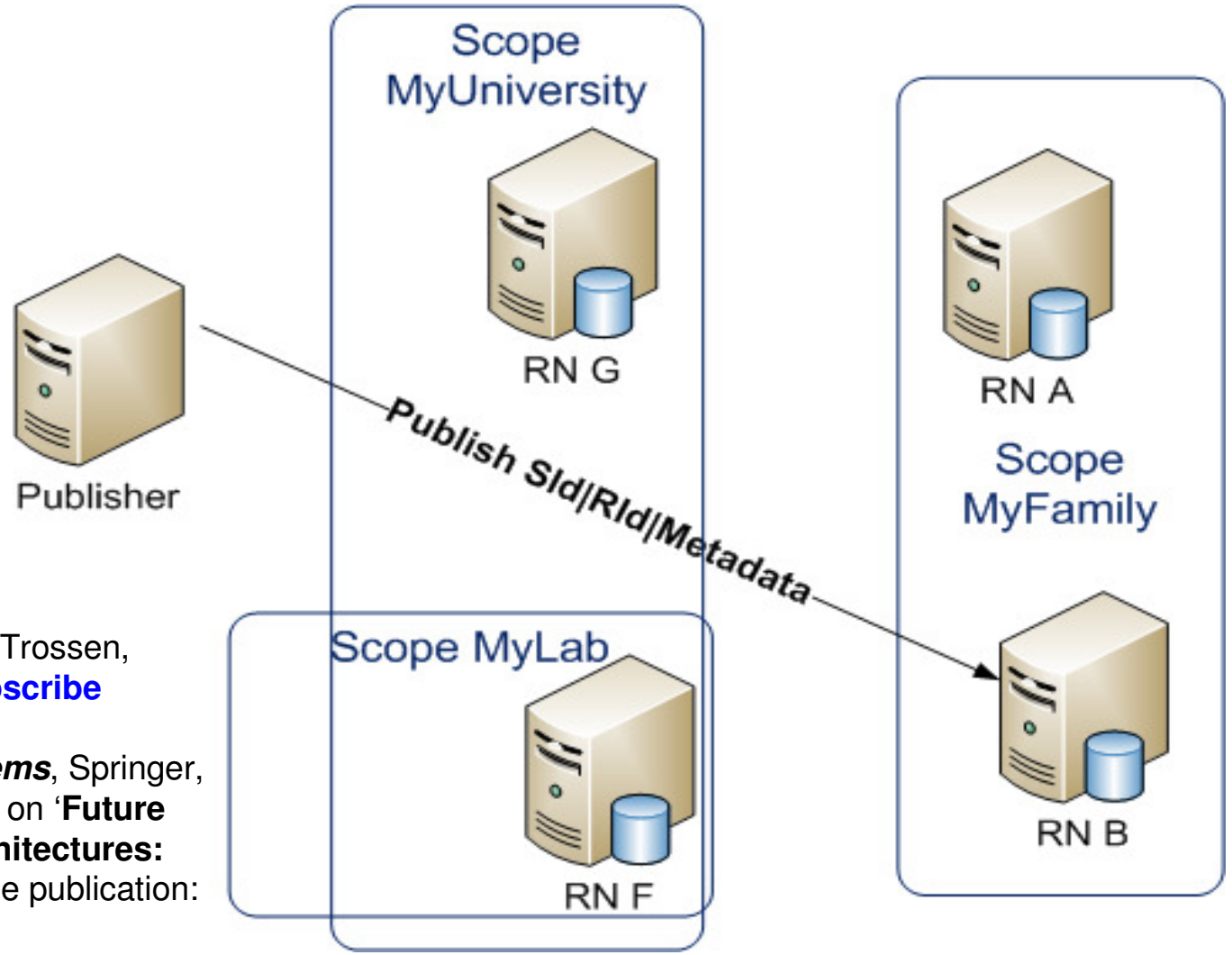
- ***R****endezvous*: Matches *publications* with *subscriptions* and initializes the forwarding process
- ***T****opology*: Monitors the network and it creates information delivery paths
- ***F****orwarding*: Implements information forwarding



# Identifiers

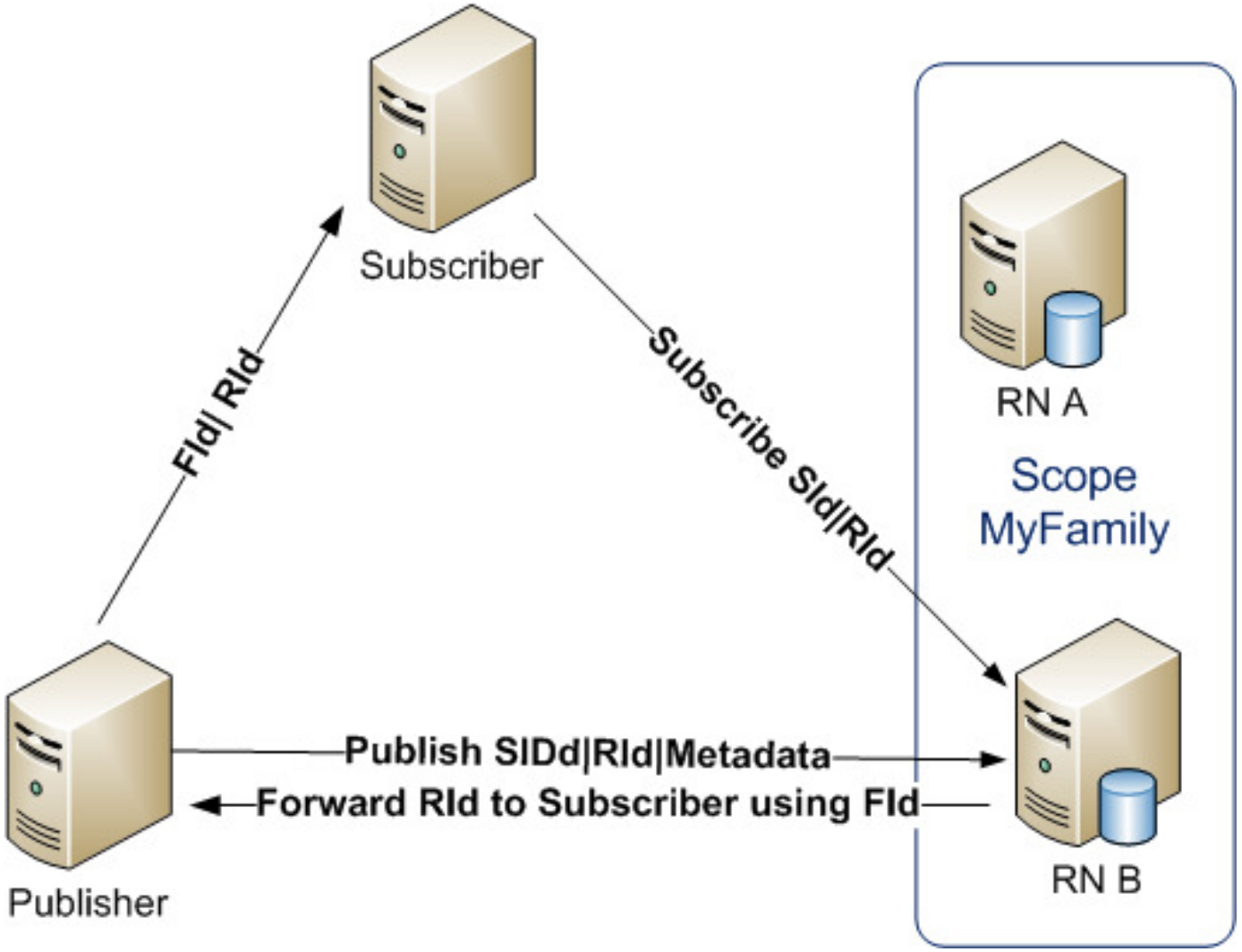


# Ψ Publication

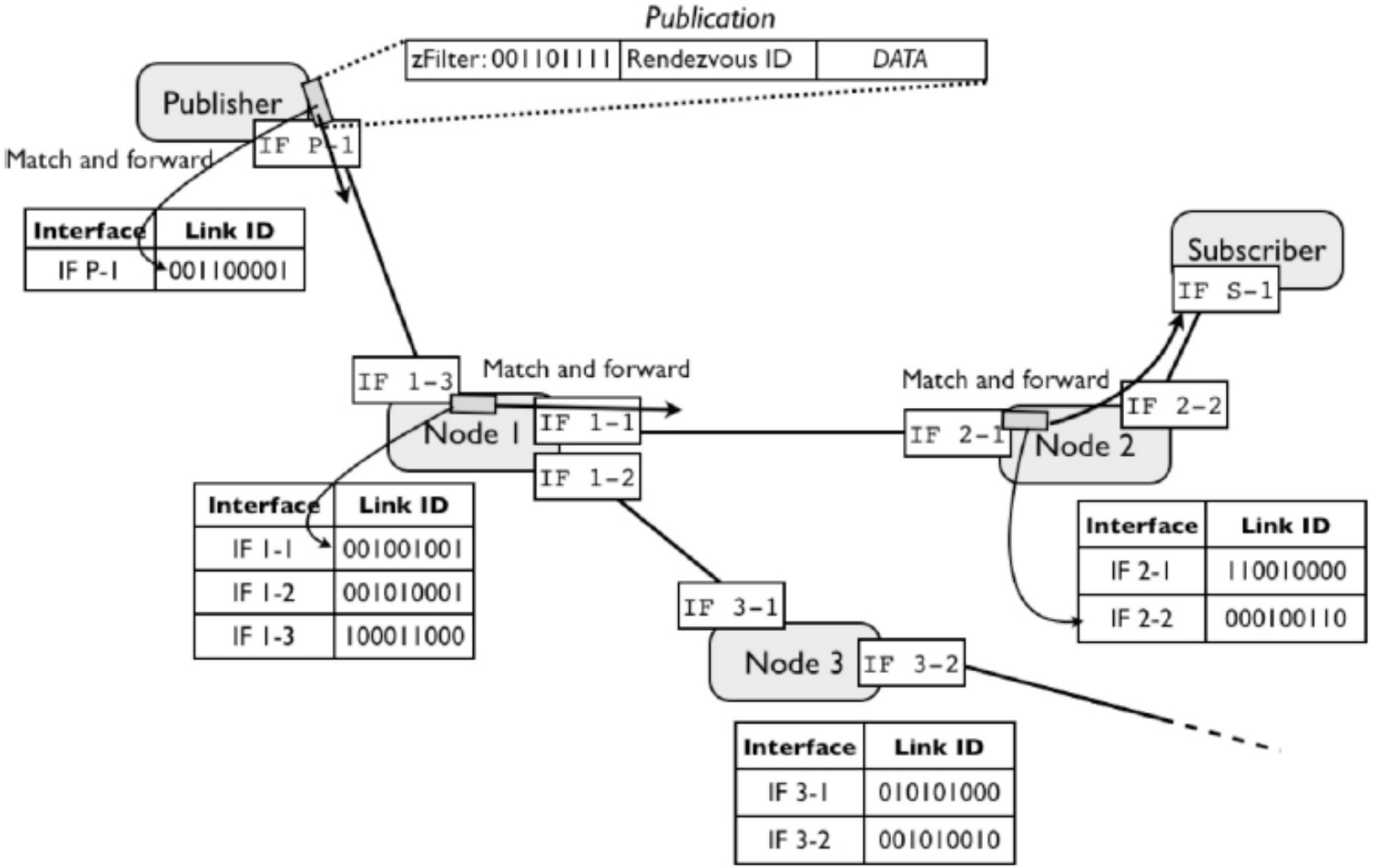



N. Fotiou, G.C. Polyzos, D. Trossen, "**Illustrating a Publish-Subscribe Internet Architecture**," ***Telecommunication Systems***, Springer, vol. 52, no. 3, Special Issue on '**Future Internet Services and Architectures: Trends and Visions**,' Online publication: 23/2/2011.

# Ψ Subscription



# zFilters Based Forwarding



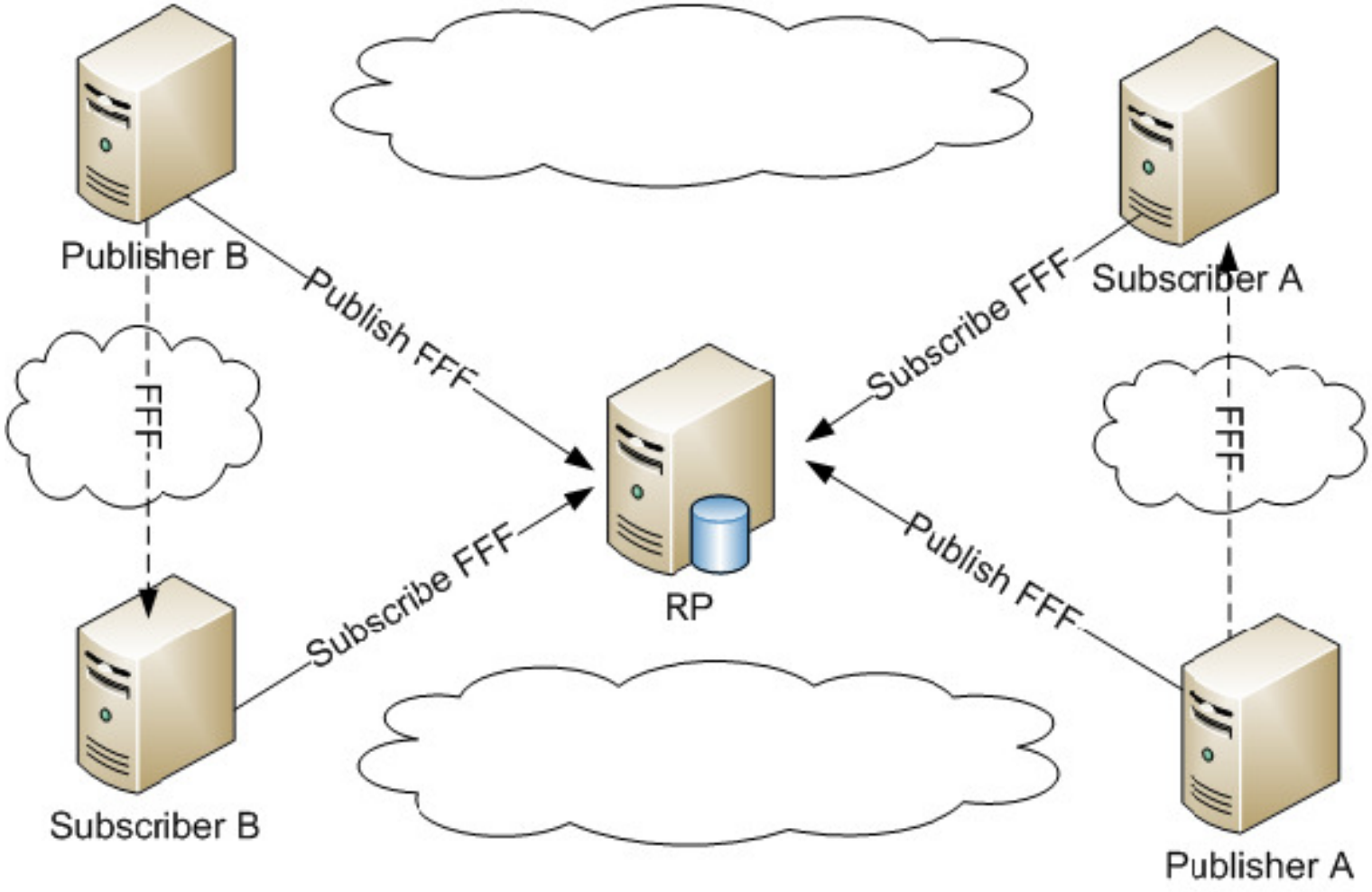
# Security Requirements

- Publications confidentiality
  - publications should be not revealed to unauthorized subscribers
- Subscription confidentiality
  - user subscriptions should be kept secret
- Integrity, Availability
- Authentication, Anonymity
- Accountability
- Information Scoping

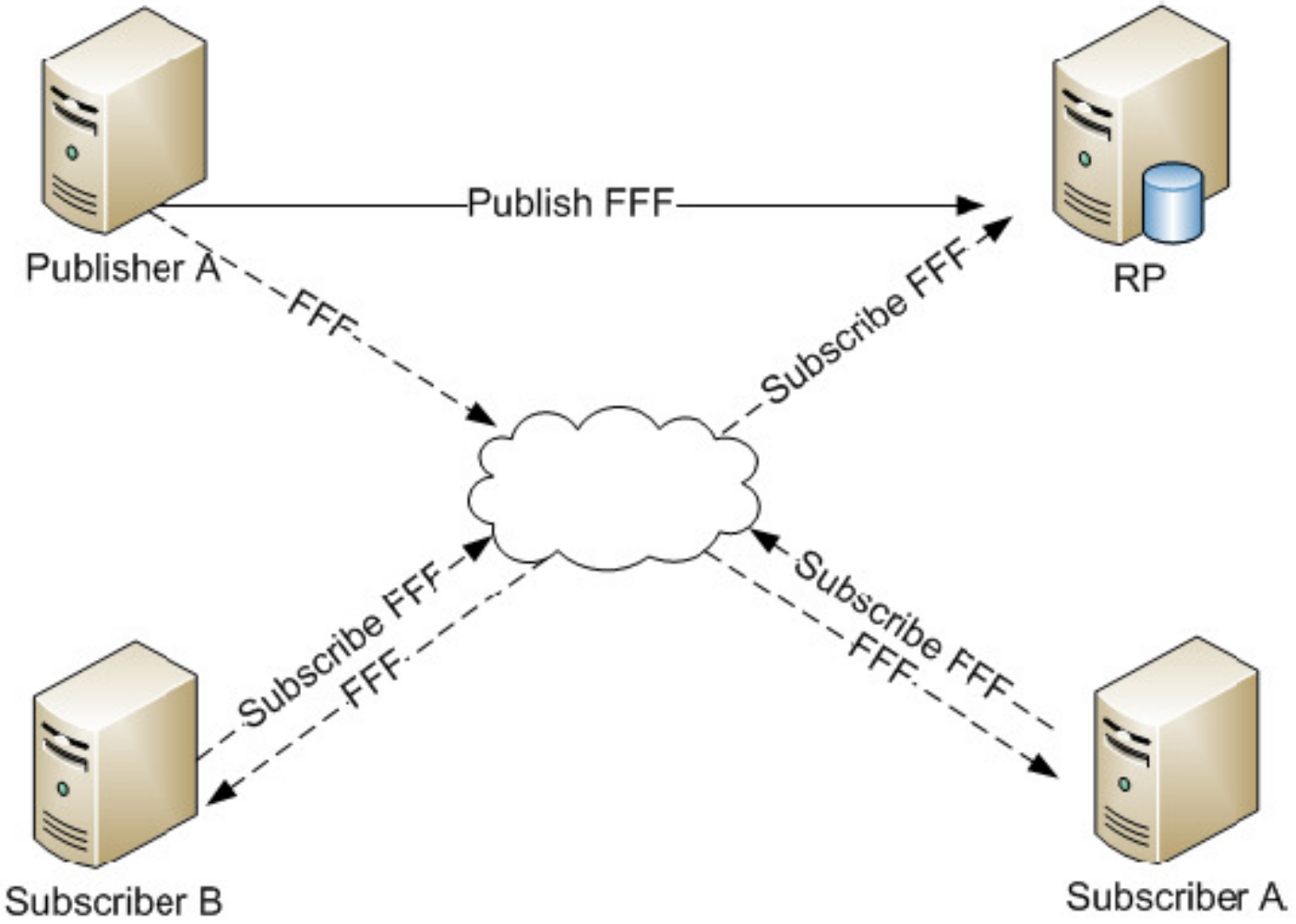
# Security Characteristics of Ψ

- Pub/Sub restores the imbalance of power between sender and receiver(s)
- No information flow until **explicit** signal for
  - Interest for specific piece of information
    - Anti-Spam mechanism
  - Availability of a specific piece of information
    - Anti-DoS mechanism
- Pub/Sub facilitates
  - Anonymity
  - Mobility
  - Multihoming
- Message aggregation
  - Resource sharing (e.g., with multicast)

# ‘Caching’ / Multiple Information Providers & Multiple Paths Example



# Resource Sharing Example



# Packet Level Authentication (PLA)

- Per packet public key cryptographic operations are possible
  - at wire speed
- The network carries only authentic data
  - Requires third-party certificates
- Need not be implemented at all nodes
  - Selected key nodes
- PLA offers significant energy efficiency
- Implemented in NetFPGAs

# Secure Forwarding Mechanism

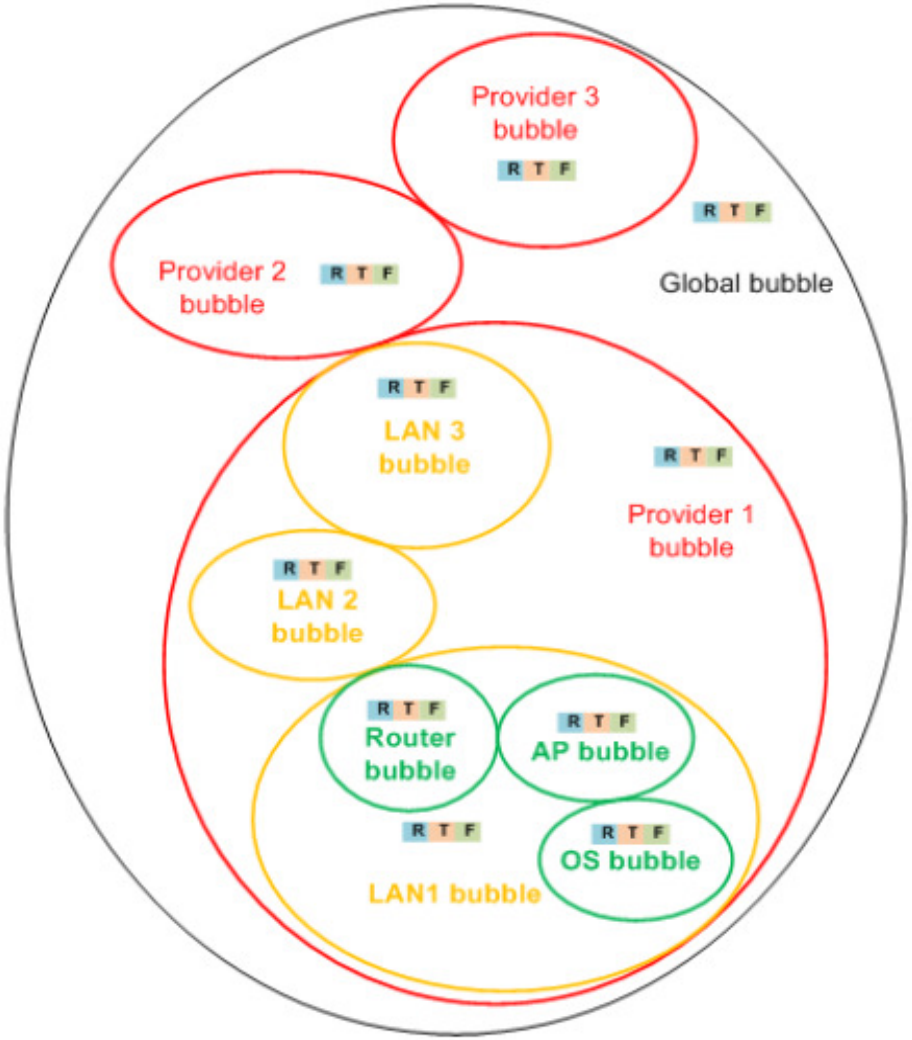
- Forwarding is based on the creation of a Bloom filter (called zFilter) that contains all the link identifiers through which a packet has to travel
- Link identifiers are unique per information flow
- zFilter creation involves an encryption mechanism
  - DoS attack resistant
  - Almost impossible to
    - redirect an information flow
    - send arbitrary packets to a destination

# Scopes: Ψ's Information *Firewalls*

- Scopes allow for information location as well as for control of information dissemination
- Can be physical….
  - e.g., a sub-network
- … or logical
  - e.g., my friends in Facebook
- In scopes, access control and accounting mechanism will be implemented

# Building Blocks in Ψ: *Bubbles*

- The ***bubble*** concept is akin to the current layering model
- The basic building block of functionality at all levels
  - from OS
  - through LAN
  - to Global Internetwork
- Bubbles offer availability and extensibility through the **recursive** execution of basic functions

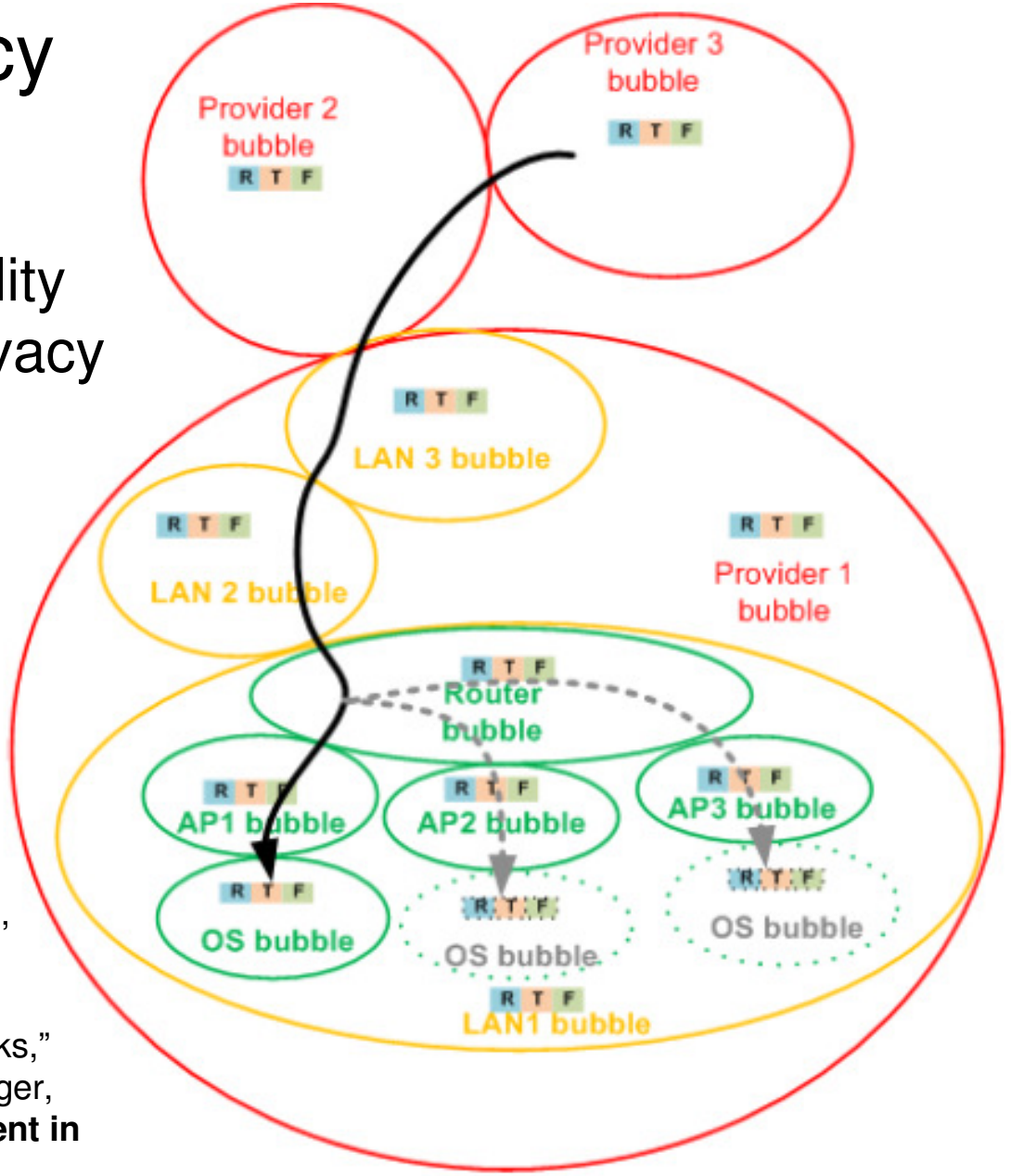


# Bubbles...

- Need to implement the 3 basic functions:
  *Rendezvous*, *Topology* and *Forwarding* (RTF)
  - Rendezvous
    - responsible for matching subscriptions with publications
  - Topology
    - monitors the network topology
    - and creates information delivery paths
  - Forwarding
    - implements information forwarding
      … throughout the delivery path(s)
- ... differently, depending on level

# Mobility and Privacy support

- Bubbles support mobility as well as location privacy

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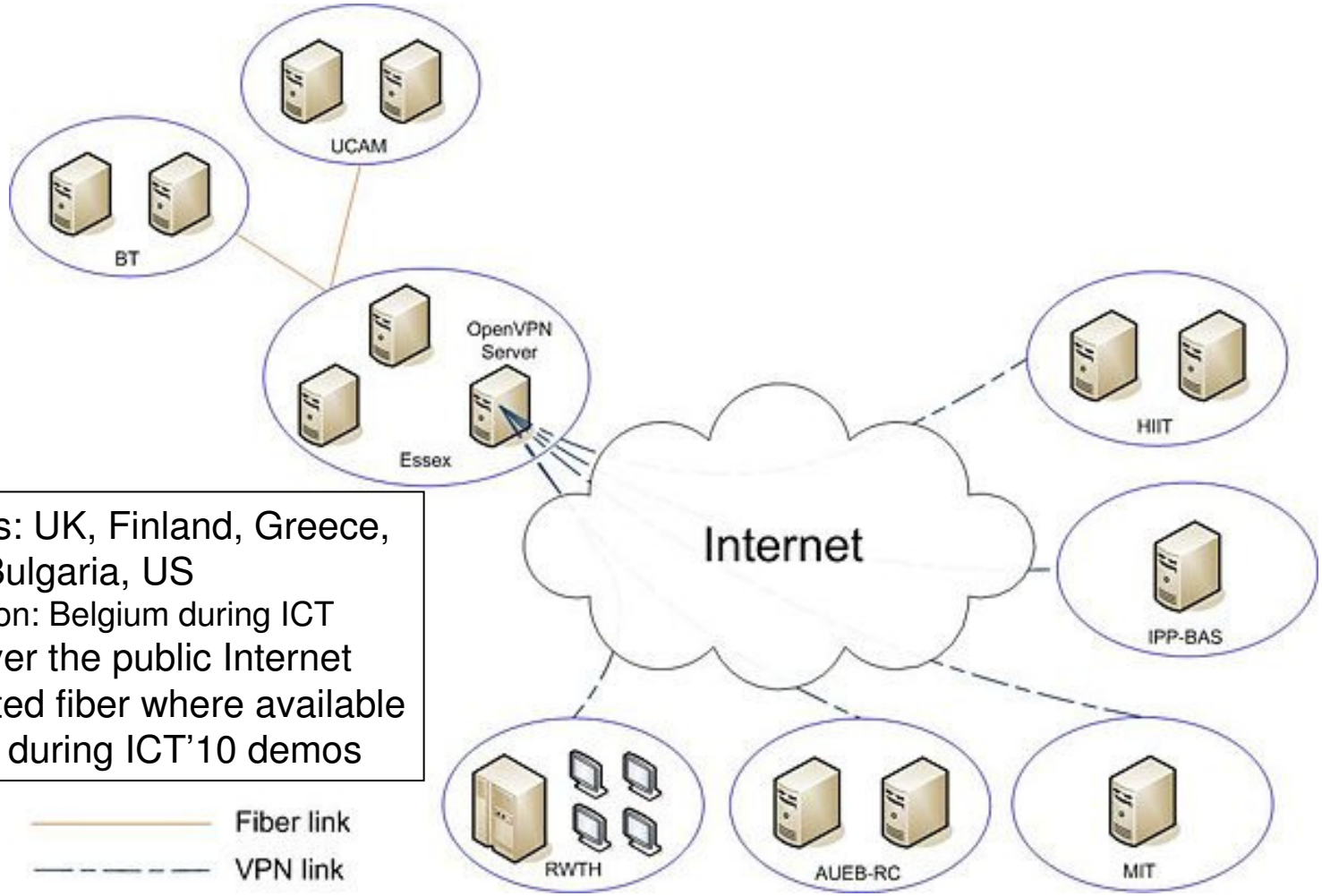
# Advantages of PSI in Mobility Support

- Publishers & Subscribers can seamlessly & simultaneously move
  - Data (packets) are identified independently from source or destination
  - Information (cached? content) is still transparently available
- Publish/Subscribe is **asynchronous** and **multicast**
  - Demand for content served without the need of the synchronous presence of a publisher (source)
  - Adapts better to frequent mobility
- Anonymity
  - subscribers and publishers remain anonymous (unlike IP)
- Routing and Forwarding
  - decoupling IDs from addressing is a major advantage
    - locations are ephemeral
    - no need for **triangular** routing
    - **ingress filtering** problem
    - **anycast** choice of the best source of content

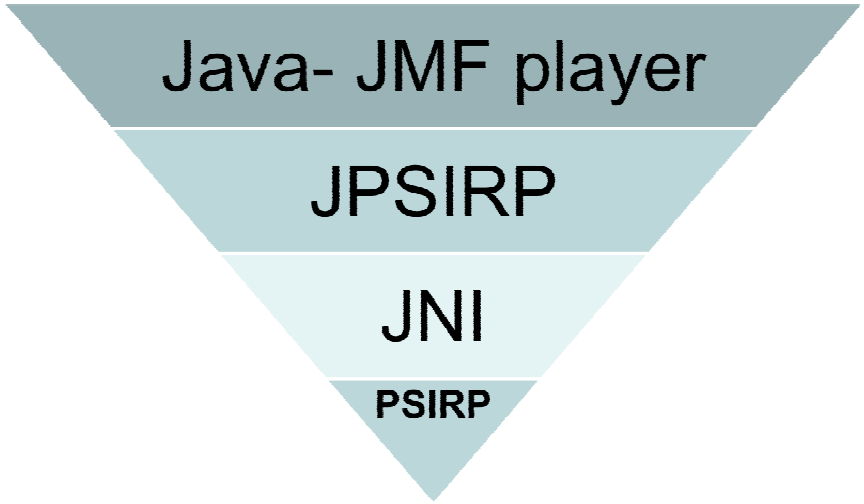
# PSIRP Testbed




- Six countries: UK, Finland, Greece, Germany, Bulgaria, US
  - In addition: Belgium during ICT
- Tunneled over the public Internet
  - dedicated fiber where available
- 5 sites used during ICT'10 demos

# Multimedia over Ψ

- Motive: Multimedia over Ψ
  - the “YouTube” of the future
- Streaming videos
  - without RTP/TCP/IP
  - only native Ψ
- Basic Components of the application:
  - **Publisher**: the owner of the video
  - **Subscriber**: the user that seeks to view the video
- Technologies Involved



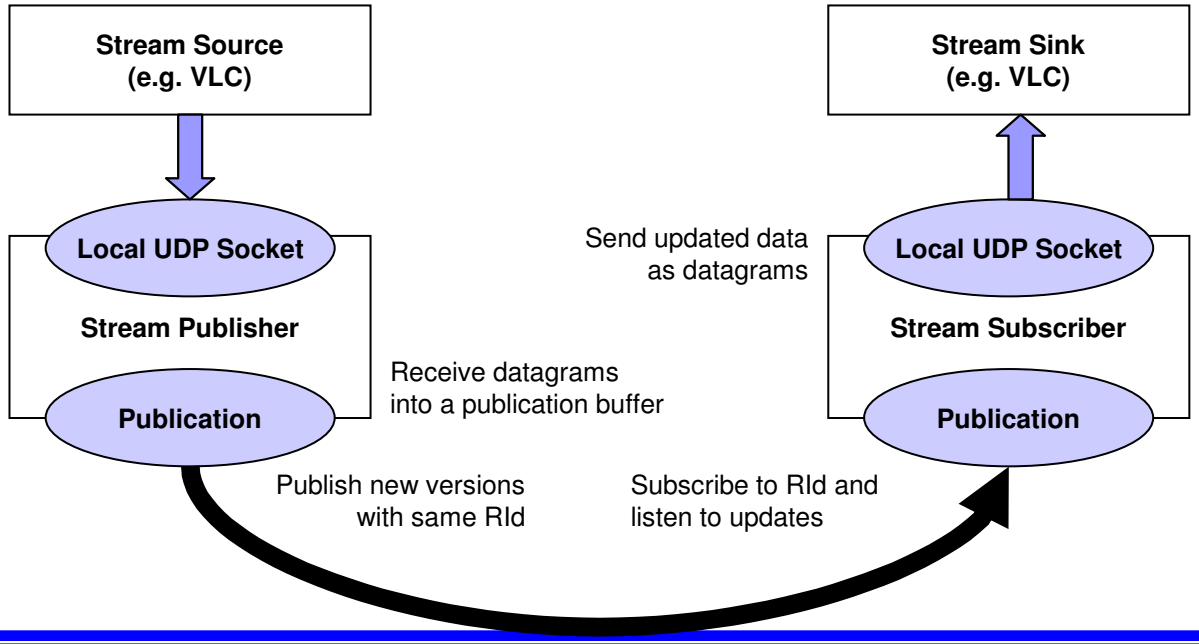

- We tried different applications
  - Video
  - Audio/voice (VoPSI)
  - ...

# Publish Videos

- Publish a video or a directory with multiple videos
- Define the scope for the video she uploads to the network
- Currently done via local exchange of video knowledge

# Subscribe to a Video

- Search for the desirable video using the name of the video
  - Currently done via local exchange of information
- Subscribe to its PSI-level identifiers
- Play the video while downloading




**NOTE:** The publisher knows the subscriber set for this RId, sends the metadata directly to the subscribers; no rendezvous. Subscriber with metadata for a new version, subscribes to the corresponding data chunks.


# The PURSUIT Project

- EU FP7 ICT STREP, 2010-2013 (http://www.fp7-pursuit.eu/)

- *information-centric* view on networking
- Focusing on *WHAT* is being exchanged
  - rather than who are exchanging it, or where it is
- Builds on the results of PSIRP
- Designing (/extending/completing) an internet architecture based on pub/sub
  - Routing
  - Security
  - Economics
  - Unification of Wireless w/ Wireline
- 8 partners from 4 EU countries: Finland, Germany, Greece and UK
  - Aalto University (FI)
  - RWTH Aachen University (DE)
  - Athens University of Economics and Business (GR)
  - University of Cambridge (UK)
  - Oy L M Ericsson Ab (FI)
  - Centre for Research and Technology Hellas (GR)
  - University of Essex (UK)
  - CTVC Ltd (GB)

# Current Work in PURSUIT

extends PSIRP's work & results

- Creation of robust & reliable rendezvous system & topology manager
  - Inter-domain rendezvous, topology, forwarding
- New Prototypes
  - PSIRP: Blackhawk; PURSUIT: Blackadder (new)
- Securing Scopes
  - and rethinking the implementation
- Deployment of a large PSIRP testbed for experimentation
  - and alternative evaluation tools
- secure naming services

# Conclusions

- ICN is better positioned to address
  - mobility, caching, security, privacy...
  - Evolution & tussles resolved at or near run-time
- The Ψ architecture inherits the advantages of ICN & the publish/subscribe paradigm
  - In particular the security ones, but….
- PSIRP selected and added specific security mechanisms
  - Packet Level Authentication
  - Secure Forwarding (zFilters)
  - Scopes
  - Bubbles
  - Information ranking

# PSI: Key Observations and Issues

- RIDs: hash of content vs. not...
  - Implications of uniquely indentifying content
    - Caching (enabled/facilitated)
- SIDs as special case of RIDs
- pub/sub “recursively”
  - at many levels of the hierarchy/network
    - from wire-level to the global Internet
    - perhaps used to realize reliable transport
- Granularity of items (to publish/subscribe to)
- pub/sub model: documents vs. channels
  - versions (& IDs) of publications?
- Algorithmic Identifiers (RIDs)
  - nice for intra-channel IDs...
- asynchronous (subscribe before publish)
- search engines probably still important (at different level?)
- Naming vs. IDs?
- Mobility, multi-homing, soft handoff...

# More Observations, Questions & Issues

- ...
- information vs. content -centric vs. named data vs. pub/sub vs. ...
- overlay vs. clean-slate
  - special-purpose nets only? Not global?
- Wireless?
- Rendezvous
  - powerful
  - trusted
    - has lots of information...
  - target of DOS attacks
  - networks of RPs = RN
  - belongs to different entities than network provider?
  - competing RN
  - RP functionality needed at multiple & different levels
    - intranet, global... on a wire...