



PSIRP
Publish-Subscribe Internet Routing Paradigm
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Final Plan for Using and Disseminating Knowledge

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1 Introduction

The PSIRP project has been re-examining the crucial fundamentals of the current Internet and creating an outline, specification, and early implementation of a possible future Internet architecture – a future that focuses on the intersection of information, security, socio-economics, and a balance of power(s) in communication.

The project has created invaluable insight into the technologies and economical aspects covering the applicability of information centric networking. This knowledge is already found its way into a number of graduate and undergraduate curricula of the academic partners of the project and a good number of thesis work motivated by the PSIRP architecture are also underway.

Industry partners are using the insight gained from PSIRP to assess the potential of the information-centric pub-sub networking approach to provide functionality beyond the traditional communication businesses and looking for opportunities in other industry segments such as media distribution, retailing, and others with an emphasis on logistics. The industry partners have studied how wider socio-economic influences would be likely to alter the evolution of the Internet.

The project results have been presented in multiple major conferences (e.g. SIGCOMM, INFOCOM etc.) to engage wider academic and commercial audiences. In accordance with EU FP7 dissemination policies, the first code release of the PSIRP framework implementation was made under the GNU Public License version 2 (GPLv2) and Berkeley Software Distribution (BSD) licenses. Moreover, the project has also made additional simulation tools publicly available and other research projects have adapted many of these items for their own purposes. A multi-site test network is under development to deepen the knowledge and demonstrate the capabilities of PSIRP's newly-developed technologies in a real-world operating environment. Furthermore, the project has been collaborating closely with a number of international and national research projects working on the future directions of the Internet.

The results and the knowledge gained through PSIRP have also been applied through a number of EU FP7 project proposals (e.g. PURSUIT and FARAMIR) and in related nationally-funded projects (e.g. ICT SHOK Future Internet program, PAL Project in the UK) to initiate supplementary research activities.

This deliverable outlines the partner-level and consortium-level plans to deepen the exploitation of the gained knowledge in the near and mid-term future.

2 Partner-level Exploitation

2.1 LMF

The in-packet Bloom Filter (iBF) based forwarding mechanism, introduced in [LIPSIN], provides a space efficient and stateless way of doing source routing in the network. Although initially specified for forwarding publish/subscribe based data in the content centric approach adopted in PSIRP, it has shown potential also in other areas, independent of the data that is transmitted over it.

In [MPSS], we show that the iBF based forwarding can enhance the performance and simplify the setup of MPLS based VPN solutions. This application of iBFs is not tied to the publish/subscribe based transmission, but it can be implemented in the existing networks with relatively low effort. If proven to work, it may be one application that can emerge from the PSIRP research.

In addition, other areas have been discussed where iBF based solutions could be applied. One interesting area are Data Centers, where the iBF based forwarding can be done internally, while externally IP based routing still is in use. Current data center computers are, more or less, located physically close to each other, providing an easy way of adapting iBF forwarding internally. In the future, when the physical location of the hosts is no longer important (cloud based computing), the publish/subscribe based ideas can further enhance the DC operations.

In addition, we work in close co-operation with Aalto University, presenting lectures in courses and disseminate the achieved research results.

2.2 BT

Fundamentally altering the internet paradigm is perceived as a challenge of monumental proportions and, therefore, one that most people would rather not consider. Attempts to modify the underlying Internet architecture have been, up until now, impossible to manifest, due to a lack of:

- Understanding (i.e., poor appreciation of what the solution entails)
- Perceived urgency (i.e., no recognized impending operational catastrophe)
- Motivation (i.e., no perceived benefit, no gap to fill etc.)

Unfortunately, conflicts of interest also arise in commercial and industrial areas because drivers such as profit and politics dominate the allocation of resources which largely shape the future of the Internet.

BT's Approach

BT has tried to address these problems in a number of ways:

1. By engaging with representatives from businesses that would benefit from an Information-centric internet, to understand their issues and drivers.
2. By extrapolating from those business insights and carrying out wider research into business motivations to derive a set of solutions that the PSIRP architecture provides for three key sector areas.
3. By considering how the Internet is likely to evolve in order to meet those demands.
4. By translating the sector drivers and solutions into dependencies on technological components.
5. By building a system dynamics model to look at tussles between interested parties in the Internet
6. By building a system dynamics model of the evolution of the Internet towards an Information Cloud, based on the PSIRP architecture, where different investment scenarios can be explored.
7. By looking at technology solutions available to BT, now, that would enable it to build towards Information Cloud-like solutions for its customers.

Business Engagement

BT had engagement discussions with representatives from the Retail Sector (TESCO) and from the Creative Industries (CCTV and GrassRoot Arts), the latter two of whom attended the PSIRP Industrial Engagement workshop. This workshop enabled key business drivers for an information-centric internet to be captured. Follow up discussions to further understand drivers

and benefits of *Information Cloud* (a terminology being used for the offerings provided by an information-centric Internet) were held with Stuart Porter of TrueTube (CCTV.) As a result, TrueTube's motivations were understood much more fully, in terms of what features of an Information Cloud were viewed as the most valuable, and how valuable these were likely to be. BT has a number of high level engagements and projects with the UK Government that give it significant insights into the issues and opportunities stemming from a PSIRP-like architecture, for the Government sector.

Further research into drivers for an information-centric internet was carried out, using a number of public sources, such as output papers from the Future Content Networks Group [FIPO] and analysis of UK Government spending on IT projects [IT]. From this research, combined with the insights gained from personal engagement, three business sector-specific 'pitches' were written, outlining the drivers and benefits of an Information Cloud solution set. The sectors addressed were *Retail, Content-Centric* and *Government*.

Evolution of the Internet

BT has considered how the Internet would be likely to evolve towards a PSIRP architecture. It is seen as highly unlikely that a systematic redesign of the Internet to a PSIRP architecture would happen in a planned way. It is seen as much more likely that there would be a number of Information Clouds that would appear with limited scope, initially – perhaps intra-enterprise only, or for a specific purpose only, such as, for example media rights distribution. Also, BT draws a distinction between what it classes as 'native' Information Cloud, which implements the full PSIRP architecture in the network, and 'shim layer' Information Cloud. This 'shim layer' is envisaged as enabling searching referencing information items using content-centric terms, but whereby these are mapped to an underlying IP infrastructure, initially. With current innovations, such as Ericsson's work on MPSS (MPLS-like LIPSIN variant), many features of this 'shim layer' are available today, and could be implemented with relative ease. However, note that even with routing issues resolved, there is still a strong requirement, in achieving Information Cloud functionality, for Packet Level Authentication to be implemented and its cost and level of performance are not yet fully known.

Modelling Routing Tussles

A system dynamics model was written to model the interested parties in network management. This was in order to understand how wider socio-economic influences, such as from the Regulator, would be likely to alter the evolution of the network over a 10 year timescale; in particular, to understand the subsequent implications for how routing would take place. This in turn informs the technology design choices, with respect to routing and networking. The findings of this model are to be presented in [D4.6].

Modelling the Evolution of the Internet

A system dynamics model was written to connect the business sector drivers to the technological components on which the solutions depend. The model links the demand for technology, with business sector investment and network investment. Simulations of scenarios can be run over 10, 20, 30 year etc timescales to explore the effect of investments on traffic growth and network transformation. 'Shim layer' and 'native' Information Cloud solutions are distinguished, according to the solutions they provide, as well as their investment costs and relative revenues. This should allow an incumbent operator, such as BT, to explore cost/benefit trade-offs in making network transformation investments, in relation to business sector demand and investment. The findings of this model are to be presented in [D4.6].

Constrained Scope Information Cloud

BT continues to work with vendors to look at current off the shelf technologies, such as message routing that would enable it to provide Information Cloud-like services to its customers, within an intra-Enterprise scope. Even without a radical re-design of the Internet, PSIRP provides us with many insights into how best to provide information services in a more flexible and more powerful way.

Message-Oriented Middleware (MOM) providers typically offer several modes of message delivery. These include sender-driven (to a queue for a receiver or group of receivers), workflow or process driven and topic-based publish/subscribe. This latter category allows us to implement applications very similarly to those that might use a future PSIRP network capability. Whereas the decoupling in PSIRP is provided through the use of a Rendezvous Identifier, instead we use a named topic channel. The topics are structured hierarchically providing some degree of subscription and management scalability (although less flexibly than PSIRP's meaningless identifiers and RId/SId information graphs). Importantly, MOM solutions typically do not consider the problem of multiple domains and peering, nor are they concerned with optimal fast forwarding paths. However, initial deployments of information networks are likely to be provided by a single service provider carrying relatively low volume traffic over a common IP network.

BT already has examples of such message based networks (such as the SPINE developed for the British NHS), and continues to look at similar deployments in other industry sectors, along with providing generic horizontal message network capability (such as already provided by BT Integrate). These deployments support both information and process/service integration, providing multiple interface paradigms (pub/sub, send-to). Whereas MOM provides an equivalent to the channel-based model of PSIRP, Content Delivery Networks, or CDNs provide a document-centric model. In this case requests for document identifiers (typically URLs) can be routed to the most appropriate information location.

Designing applications using the REST (Representational State Transfer) principles allows service or application integration tasks to be devolved into a more information-centric model. Instead of using coarse service interfaces, REST uses simple actions (e.g. PUT, GET) on items of (dynamic) information. Hence, this style of applications maps very easily to a PSIRP network model instead of using a more typical tracker and HTTP/DNS/IP network. In a transition to a PSIRP network, edge pub/sub capability (such as Atom Pub/Sub) along with mobility would be directly supported by the PSIRP network and become much more scalable.

In conclusion, although there are no direct exploitation plans for PSIRP, the style of application development seen within the industry is moving in a direction that will make future identifier-based and pub/sub networks more valuable. Large scale peering and optimal use of the network forwarding fabric will also become essential once there are significant single-domain deployments.

2.3 NSN

According to Nokia Siemens Networks' long-term view the Communications Service Providers (CSPs) can transform the way they work and behave to bring the individual user experience to a new level in a most cost efficient way. One of the main factors affecting the transformation is explosion of traffic amounts, both in fixed and mobile networks. The traffic amounts will reach unseen levels, requiring new investment in capacity, as well as upgrades to new technology such as LTE. Yet, the increased traffic will not bring correspondingly higher revenues and, combined with the increased investment needed, will put great pressure on CSPs' profitability. In order to ensure sustainability of the networking ecosystem NSN is particularly interested in new architectures and systems that promise scalability benefits with controlled and manageable OPEX costs. This means that OPEX should grow significantly lower than the number of subscribers or traffic volumes. Information centric networking as envisioned and experimented by the PSIRP-project promises the needed efficiency and cost benefits. NSN

interest is to develop, evaluate and prototype these concepts and tools as part of existing and future network architectures or as additional services. Pub/sub architecture is one element in the larger scheme of the network evolution.

The experimental work done in the PSIRP project complements related activities within the company by exploring architectural alternatives for media distribution services. Media distribution is traditionally done through dedicated networks (e.g. CATV, DVB-T), but also increasingly as an application on IP networks (IPTV). The dedicated networks and IP networks are fundamentally different, and it is likely that straight-forward adoption of the current IP networks for media distribution will not yield the best possible outcome (e.g. resource utilization, service quality). The Publish/Subscribe Internet Routing Paradigm being investigated in the PSIRP project is one promising architecture alternative, where the media itself, not the physical nodes in the network, are in the center of the network functionality. NSN is evaluating the utility of the PSIRP architecture for future media distribution scenarios. NSN sees the name-based routing architecture (rendezvous) in PSIRP as a promising platform for future networking regardless of the underlying networking technologies (pub/sub or legacy networks), as it captures the pub/sub service model being provided to applications, and allows for rich policy, metadata and context mediated coordination between clients and the available services in the network.

The inter-domain aspect of the PSIRP architecture emphasizes the functional co-operation between competing network operators. Understanding the potential shifts in the inter-operator interface in the future may prove fundamental for the telecom and datacom business environment. Even seemingly small changes in the incentive structure, as likely resulting from fully-developed data oriented networking architecture, may lead to game-changing effects in the global network business landscape. However, as such changes happen over time, it is essential that the PSIRP architecture would be compatible with the current network business structure to begin with.

NSN has published together with the other project members a number of research papers in high level conferences. One IPR has been filed for patenting. More over, the knowledge gained about information centric networking and, in particular, the developed rendezvous system has resulted in related and complementing activities in a nationally funded research project (Tekes ICT SHOK Future Internet program) as well as contributions into EU FP7 call 5 proposals.

2.4 AUEB-RC

Dissemination of PSIRP results

AUEB-RC has published, often in collaboration with other partners, 13 papers in refereed workshops and conferences. Additional conference papers are in preparation, while some of the published papers are being reworked for submission to journals. The MMLab Web site includes a separate page for PSIRP and its results, while preprint versions of all our papers have been made available as technical reports from our Web site. We have also presented the project and its results in invited panel discussions at various conferences and events (e.g., at the ICT Mobile Summit, Santander, Spain, June 2009, on the panel: 'Towards a Mobile-friendly Internet,' at the IEEE PIMRC 2008 Panel: 'Building the Internet of the Future – The Wireless Challenge,' etc.). Finally, we have presented the project and its challenges at our departmental Research Day and in our yearly graduate seminar on Computer Science Research, with the goal of attracting additional graduate students to the PSIRP project, something that has already paid off.

The BitTorrent Simulator

As part of our work on overlay multicast routing and mobility support, we extended the OMNeT++ simulator to better reflect Internet scale topologies and wrote the first fully detailed packet level simulator for the BitTorrent protocol suite, developed with partial support from the project as a benchmark against which to assess the content distribution performance of the PSIRP architecture. The software was presented in a specialized simulation conference (IEEE/ACM MASCOTS) and is being distributed with an open source license via a dedicated page (<http://mm.aueb.gr/research/bittorrent/>) citing the project's support, which is also referenced from the main OMNeT++ Web site. The software is in active maintenance, with two mailing lists established to support users and developers. It has already been downloaded many times (more than 100) and we expect it to gain additional visibility after it appears in work by other researchers. The simulator has already been used in the context of FP7 project 4WARD, as documented in 4WARD deliverable D6.2 (Second NetInf Architecture Description), as part of their simulation based evaluation of the NetInf Architecture produced by that project.

Exploitation in Teaching

The areas explored in the context of this project have already found their way into our graduate and undergraduate curricula. In particular, our undergraduate and graduate Distributed Systems courses were considerably extended to address content based routing and content centric networking during the first year of the project, while the publish / subscribe communication paradigm was introduced to the graduate course during the second year of the project. For the required programming project of this class the students worked on content based routing, so as to have the background to work on more advanced topics in later courses. In the graduate course Topics in Multimedia Systems, PSIRP was presented as a possible avenue for class projects, with two student groups undertaking PSIRP related work:

- The first project focuses on real-time bidirectional continuous media communication over PSIRP, developing a PSIRP-compatible Internet telephony application where the two communication endpoints are, at the same time, publishers and subscribers.
- The second project develops a video streaming application over PSIRP, where the content provider publishes video files in "chunks" (e.g., video frames), also publishing a "map" of the chunks the stream is composed of as a separate publication. The end-user first subscribes to the stream map and then to the chunks that correspond to that stream (or actually, any subset it is interested in, in order to, say, skip frames).

The goal is for some of these students to continue their work with PSIRP in their MSc theses. Wireless oriented pub/sub based projects are also planned for the Wireless Communications and Mobile Computing graduate course in the next academic year.

Thesis Work

Four MSc students have completed theses related to PSIRP in 2008-2009, in topics such as:

- Simulator implementation and evaluation of Hierarchical Chord to be used as a basis for the PSIRP overlay implementation.
- Simulator evaluation of overlay multicast based mobility support in realistic wireless network topologies with real life user mobility traces.
- Design of Denial of Service attack prevention schemes for publish/subscribe networks based on cryptographic client puzzles.
- Design of anti-spamming schemes for publish/subscribe systems based on asymmetric cryptography and digital certificates.

Two MSc students are currently working on PSIRP related subjects in 2009-2010, in topics such as:

- Gossip based information dissemination over publish/subscribe networks.
- Implementation and evaluation of publish/subscribe applications over a wide area test bed.

We expect to supervise a similar number in 2010-2011. One BSc student also completed a thesis related to PSIRP in 2009-2010, designing and implementing a socket emulator for the PSIRP prototype, as well as a simple file transfer application to be used as a demonstrator. We expect two more B.S. students to work on PSIRP related subjects in 2010-2011. Finally, we recruited one new PhD student in 2008-2009 to work on content distribution over the publish / subscribe paradigm, with two more PhD students in 2009-2010 to work on the architecture and implementation of the PSIRP transport and the rendezvous network. Two additional PhD students are working in the project from the beginning, one in the overlay based implementation of the PSIRP principles and one in the security, trust and reputation aspects of PSIRP.

Future Research & Test Bed

Our involvement in PSIRP so far has considerably strengthened our competitiveness not only in new communication paradigms such as publish / subscribe, but also in distributed systems, and in particular in clean slate Internet design, large scale content distribution, support for mobility, trust structures and publish / subscribe security. In order to perform wide area experiments at a larger scale, we participate with two nodes in the PSIRP test bed that is currently being created between project partner sites. As part of the test bed creation exercise, we are working on the interconnection structure both for the dedicated PSIRP test bed and for a possible PSIRP over PlanetLab Europe overlay test bed.

2.5 IPP-BAS

On academic level, overview of PSIRP concepts and ideas are included a MSc course titled "Global networks" in New Bulgarian University (NBU) at the end of the spring semesters each year. The course is part of "Software technologies in Internet" MSc specialty area. The course is conducted as a seminar and discussions from 6 to 8 hours at the end of semester. The instructor suggests practical course problems based on PSIRP topics. The seminar approach is more suitable for us, compared to the development and certification of a whole dedicated PSIRP course of at least 30 hours, as the administrative procedure for accepting a new master course is hard and usually takes more than one year. Similar types of events are planned for the next academic year for other MSc level courses with networking related subjects as well. One MSc student is directly involved in the project.

Project presentations on PSIRP achievements and status are being held regularly in the technical meetings of network administrators, supporters and developers involved into Bulgarian Research and Education Network (BREN) activities and GEANT project. Similar short seminars are conducted in other research institutes in ICT area.

On an industry level, IPP-BAS organized a seminar during the large annual exhibition "ICT days '2010" in Sofia. More than 100 private and public ICT companies participate in this event which was a good opportunity to educate the industry about the PSIRP achievements. Printed project materials were available during the whole exhibition.

For the purpose of exploiting the functionality of the Blackhawk prototype IPP-BAS has developed a set of scripts for fast building and configuring a network of virtual machines running Blackhawk software. The purpose of those scripts is to ease developers in testing, evaluating and demonstrating the PSIRP architecture using a small number of computers. Based on open source software the scripts can give good performance results. A user

interface for executing testing scenarios and gathering results in a user-friendly way is under development.

IPP-BAS plans to use the PSIRP test bed (see section 4) to evaluate the traffic/congestion control (TCC) implementations developed at IPP-BAS and to measure congestion control algorithms parameters (state, responsiveness, etc.) in different test case scenarios.

2.6 RWTH Aachen University

The exploitation of PSIRP results at RWTH Aachen University will take place by further exploring the application of publish-subscribe communications in the wireless space, as well as incorporating PSIRP outcomes into teaching. Exploitation of the results in our research work includes both wider incorporation of publish-subscribe as a communication infrastructure in other research projects, as well as further direct continuation of the work carried out in PSIRP.

In the research domain, exploitation of the knowledge we have gathered on publish-subscribe communications in PSIRP has already started with very good results. As exploitation platforms we are using our ongoing and upcoming research projects in the domains of cognitive wireless networks and wireless sensing, both natural application areas for pub/sub. For example, in the European FARAMIR project started in the beginning of 2010 we are specifically looking into the potential of using publish-subscribe communications for the exchange of measurement data in cognitive networks and towards an infrastructure for storing radio measurement data. We are also exploiting the PSIRP results in our industry collaboration projects. We have recently concluded a direct one-year collaboration with an industry partner studying the usage scenarios and potential impact of pub/sub in large-scale wireless and mobile networks. Continuation activities in this space are currently being planned.

We are also planning direct exploitation activities for the software components and designs RWTH has developed or contributed to within PSIRP. Key example in this space is the topology management framework developed within WP3. The topology management framework, while targeting fixed networks, was explicitly designed to be extendible to diverse network types. We are specifically planning to study in the future issues related to topology management in wireless networks, and to extend this work towards more complete radio resource management solutions built on pub/sub communications. Some of these activities will take place in the context of the European PURSUIT project that will start later in 2010, but we are also expecting to carry out portions of these activities directly as part of our core research. The university has had also a direct exploitation in the form of a consultancy project in the domain of wireless pub-sub architectures, which has been aimed towards explaining the customer the benefits and possibilities opened by such technologies. Finally, there is also active ongoing planning on the dissemination and exploitation possibilities on the domain of topology control related software and algorithms that have been benefiting from PSIRP research.

In teaching we are exploiting PSIRP results by incorporating new developments in information-centric networking and publish-subscribe communications into our course on "Ad Hoc Networks and Mobile Computing". The work in PSIRP is also directly exploited in the PhD thesis work of two of our doctoral students, one of which is directly focusing on pub/sub-communications. In addition, we are incorporating information networking as a key paradigm to consider in the design of cognitive wireless networks in an advanced course given on the topic for the first time in the summer semester of 2010.

2.7 TKK-HIIT

Following our earlier dissemination efforts within both the research and commercial communities, we have created academic course-based means for the dissemination of PSIRP

developments, in order to educate the general public and to spur open application development efforts. In this, we aspired to create a supportive learning environment where the innovations of PSIRP's clean-slate approach could be discussed and evaluated. Two successive special-topic courses were instituted during the spring 2010 term within the Faculty of Information and Natural Sciences at Aalto University in Espoo, Finland. These courses were targeted towards advanced graduate and post-graduate students with a diverse background in ICT.

A panel of experts with extensive experience within the PSIRP project and related fields were invited to oversee the design, operation, and conclusion of these courses. Through the application of documented systematic forecasting and consensus techniques (e.g. the Delphi Method), this panel of experts has thoroughly overseen the following key tasks:

- Design and validation of the courses' structure, content, operating methods, and assessment measures.
- Monitoring the instruction and progression of the courses.
- Documentation and analysis of the performance of the courses based on participant submissions and feedback, and comments from overseeing staff.
- Assessing the feedback from the students to determine the suitability of this approach towards exploiting PSIRP's clean-slate internetworking architecture.

The validity of this approach has been verified by the Center of Excellence at the Aalto University School of Science and Technology as nominated by the National Academy of Finland.

Course #1 – Information Dissemination

Operating Objectives

The need for PSIRP and the functionality it provides is deeply rooted in the idiosyncrasies of the current Internet. The Internet's current problems, attempted solutions, operating conditions, usage demands, developmental history etc. also serve as a basis to guide PSIRP's development. As such, it was agreed early in the planning stages of the course that we would need to give the participants a suitable amount of background in these areas in order to create a proper foundation to introduce the PSIRP project and facilitate the dissemination of its components. Our research into the aforementioned background led to the following operating objectives:

- 1) Provide a brief history of the Internet that highlights how the events surrounding its inception and the demands of users at the time contributed to its foundational endpoint-centric send-receive design.
- 2) Highlight milestone modifications during the past 40 years of Internet development and characterize their evolutionary nature in response to impending operational limitations.
- 3) Demonstrate that the core Internet architecture has essentially become ossified as a result of various technical and socio-economics conditions.
- 4) Identify notable problems plaguing the current Internet as a result of modern usage demands, introduce notable evolutionary and revolutionary solution proposals, and through this demonstrate the plausible need for a revolutionary clean-slate redesign.
- 5) Provide a comprehensive overview of the FP7 PSIRP project which includes the foundations of its information-centric pub-sub communication paradigm, design tenets,

architectural components, prototype implementations, future outlooks etc., and conclude with practical demonstrations and a panel discussion.

These objectives were formulated based on the academic experience of project staff and the expert panel with the primary purpose of creating a beneficial learning environment and achieving the strategic long-term goals of PSIRP's exploitation effort.

Structure and Content Selection

Inception of the Internet – Weighting: ~5%

The origins of the Internet and its underlying send-receive paradigm ultimately prompted its developmental design stages and modern-day problems. It is thus imperative that course participants have a solid grasp of this material before the Internet's modern problems and potential solutions are introduced.

Internet development – Weighting: ~5%

Subsequent to gaining an understanding of the Internet's inception, it is necessary to understand the major developmental stages of the Internet that took place in response to the interplay between the Internet's original design, evolutionary growth, and evolving usage demands. These architectural changes effectively sustained the architecture and enabled the ubiquitous global network that is observed today.

Internet ossification – Weighting: ~5%

The inception of the Internet's endpoint-centric send-receive foundations and its subsequent developmental changes led to its current state of ossification in response to evolving usage demands and socioeconomic trends. This portion of the course illustrates the nature of these evolutionary developments (i.e. last-minute evolutions) and the circumstances that prompted their implementation (i.e. critical operational limitations), culminating in the rigidity of the Internet's core protocol stack. This information serves as a foundation by which the Internet's key problems, attempted evolutionary solutions, and proposed revolutionary solutions, can be introduced.

Internet problems and solutions – Weighting: ~5%

This section serves to exemplify the end results of the Internet's ossification and the apparent need for revolutionary progression. The Internet's prominent problems and evolutionary solutions are relatively easy to characterize to the intended audience, all of whom have an awareness of these issues due to their background in accordance with the course prerequisites.

PSIRP dissemination – Weighting: ~80%

We devoted a majority of the course lectures to the PSIRP exploitation effort, covering the state-of-the-art, general aspects of the PSIRP architecture (e.g. information centrism, publish-subscribe communication etc.), PSIRP architectural components, prototype implementations, and other key focal areas such as security and mobility. These subjects were selected by course staff and the expert panel according to their immediate relevance.

The final two lectures included a hands-on demonstration of the PSIRP Blackhawk prototype and a panel discussion involving key project staff. The purpose of these sessions was to provide a tangible demonstration of PSIRP technologies followed by a structured open-ended

discussion, allowing participants and experienced staff to interact, exchange ideas, discuss future work etc.

Results

Participant performance was very good overall; participants were generally quite adept at picking up the main points of each lecture and summarizing what they felt they had learned. The students also showed a good degree of resiliency and insightfulness in their assignment submissions. They correctly identified the Internet's notable problems and evolutionary and revolutionary solutions, and exhibited an excellent understanding of the intricacies of endpoint-centric send-receive communications as well as PSIRP's information-centric pub-sub approach. We were also very pleased with the students' ability to explain the PSIRP architecture and its components. Participant submissions contained a good degree of depth and appropriate technical explanations covering the state-of-the-art and areas such as PSIRP identifiers, rendezvous and scoping, the Blackhawk prototype, zFilter forwarding etc.

Based on the judgments of the course staff and expert panel, we can conclude to a reasonable degree of certainty that students profited from the course and gained a level of understanding that is certainly not worse than that which is typically observed from traditional academic courses in ICT.

Course #2 – Application Development

The special-topic course on pub-sub application development is an attempt at disseminating the project material through active hands-on application development using PSIRP's Blackhawk prototype. This type of course will allow us to determine the user-friendliness of the PSIRP paradigm and gauge its potential for success in the open development community. Another primary goal is to gain preliminary performance measures pertaining to the paradigm's ability to handle existing communication needs and developer methods.

Operating objectives

The following operating objectives have been devised:

- 1) Provide several instruction sessions outlining the nature of PSIRP's information-centric publish-subscribe networking approach and the functionality of the Blackhawk prototype and available APIs.
- 2) Assign participants a series of development projects designed to give a comprehensive view of the capabilities of information-centric pub-sub internetworking.
- 3) Arrange a creative open environment which gives course participants the freedom to experiment with the Blackhawk prototype and employ the API to develop unique applications and services according to their own ideas.
- 4) Provide supportive assessment meetings in which participants freely demonstrate, analyze, and constructively evaluate their solutions.

As with the information dissemination course, we intend to focus on creating a stress-free open development environment that encourages participants to take an active interest in the codecamp and avoid working towards a static staff-defined performance baseline. Most importantly, participants who present ambitious applications and services will be allowed to continue development beyond the end of the codecamp and receive additional ECTS credits for their efforts. With this, we hope to not only gauge the suitability of the prototype towards

existing internetworking needs, but also promote its progression through creativity and innovation.

The course will start at the end of April 2010.

NordSec Conference

The PSIRP project fielded an entry in the student poster presentation at the 14th Nordic Conference on Secure IT Systems at the University of Oslo in October, 2009. The poster and presentation team were very well-received and ranked 2nd overall in the competition. TKK-HIIT is an active member of NordSec and the lead institution of the associated NordSecMob Erasmus Mundus Graduate Programme in Security and Mobile Computing, and both NordSec and NordSecMob are useful venues for continued academic dissemination and exploitation beyond the conclusion of the PSIRP project. NordSec participation is already freely open for NordSecMob students, and tentative plans are being made to make the PSIRP courses and presentation of related material within NordSec standard options for future student intakes. We aspire that this will provide a useful outlet for project results during the coming years.

2.8 University of Cambridge

As a PSIRP partner, the University of Cambridge has only joined the project effective January 1st, 2010.

However, informal collaborations have existed before and will now be deepened during the formal project participation. During the remaining project participation, the following activities are planned for exploitation:

- Seminar presentations at the Computer Laboratory on various PSIRP research topics: a first seminar was held on March 18th with a focus on the ongoing transport work in PSIRP. Another seminar is going to follow on June 3rd with a focus on the socio-economic evaluation in PSIRP. Seminars are usually attended by faculty as well as computer science students in various stages of their studies.
- Master students: Master student projects are being advertised as a consequence of UCAM's formal participation in PSIRP. These target various topics in the transport and identifier area. Although the fruits of this work will not be finalized before the formal end of PSIRP, the achieved education of young researchers still counts as a form of exploitation of the work done in PSIRP.
- PhD students: Also in preparation to following efforts in the PSIRP area, PhD student posts have been advertised with a focus on rendezvous and evaluation work within PSIRP and following efforts.
- Course development: several interests have been raised for course development in PSIRP-relevant areas. The NetFPGA area, a strong development in Cambridge, is a natural target for such development. Plans are being discussed to integrate the PSIRP work into the current NetFPGA course. There are also plans to build on the course development done at HIIT for a future course on pub/sub (note that Cambridge has a long history in teaching in this area, giving the work done in, e.g., Hermes). Last but not least, the successful seminar on socio-economics, held at HIIT in September 2009, is planned to continue at UCAM throughout 2010/2011. With the course lecturer Dirk Trossen having joined UCAM, such course development is easy to implement.
- Engagement: in relation to the PSIRP work, Dirk Trossen has taken up a position as a visiting scientist in the Advanced Network Architecture (ANA) group at MIT CSAIL. This work is in direct relation to disseminating the vision and architectural concepts that are the foundation of PSIRP. This will include working with NSF-funded scientists as well as doctoral students at MIT.

- Testbed build-up: Cambridge is currently establishing a link to Essex University through a dark fibre, therefore connecting to the growing PSIRP test bed. A student is dedicated to this work, setting up the necessary hard- and software.

In addition to the above mentioned efforts, Cambridge University is also participating in the UK-funded project PAL project with two PhD and post-doc positions in this area (see Section 4).

3 Exploitation through Collaboration

Another form of exploitation is through collaboration with various other efforts in which PSIRP aspects play a major role. With this, we can push exploitation of PSIRP knowledge and technology forward beyond the current partners of PSIRP.

We only highlight a few very direct collaborations here, for more information on collaborations we refer to [D5.4] and [D5.3].

3.1 UK Project PAL

A direct form of exploitation is the integration of PSIRP results into the UK-funded project PAL (<http://www.palproject.org.uk>). This project is situated in the pervasive health area. The project utilises the increasing means for ambient sensing but also information from various data sources like email and calendars in order to better inform the end user of lifestyle choices being made and their influences on conditions like stress, obesity or others. PSIRP technology has a strong position in this project since the long-term view of the necessary communication architecture for such services is based on PSIRP's routing substrate being developed. For this, PSIRP concepts are directly embedded into the overall architecture of the PAL project. Also, technology being developed in PSIRP is being utilised in PAL, e.g., through the Blackhawk node architecture [D3.5]. The PAL project also utilises part of the PSIRP test bed, specifically between Essex and Cambridge University.

The current project partners are Essex and Cambridge University with 6 PhD and Post-doc level students being dedicated to the various aspects of the project. Dirk Trossen (UCAM) serves as the main bridge between both projects as the technical lead of PAL and the technical manager of PSIRP.

3.2 MIT Communications Futures Programme

The Communications Futures Programme at MIT is a sponsored consortium studying various aspects of the future communication value chain. Specifically the Privacy and Security Working Group, until recently co-chaired by Dirk Trossen (UCAM), has had a focus on PSIRP's vision of information-centric networking in the area of identity and privacy. The whitepaper published by the working group in 2007 on identity in the Future Internet is directly based on the vision and concepts of PSIRP [MIT]. With this, we ensure a dissemination of PSIRP's viewpoints and achievements to influential parties outside PSIRP. Examples for these are Cisco, Telecom Italia, Telefonica and Huawei.

PSIRP is currently working on strengthening this link through a physical network connection to MIT in our growing test bed. This would allow for work but also demos to be performed within this forum.

3.3 Collaboration with NSF Funded US Projects

There are several opportunities to disseminate the knowledge acquired in PSIRP towards the US academic research scene through collaboration with NSF-funded US efforts. One such possibility is the recently announced FIA (Future Internet Architecture) call of the NSF, calling for establishment of larger integrated projects in the architectural space. PSIRP's architectural

concepts have a lot to offer in this space for collaboration. One possible avenue for dissemination is through a recent appointment of Dirk Trossen as a Visiting Scientist at Advanced Network Architecture group at MIT CSAIL. This opens the possibility to directly collaborate in NSF projects (although without direct funding possibility) as a co-investigator. Some of these possibilities are currently explored.

4 Test Bed Facilities

Another avenue for the usage and dissemination of the PSIRP knowledge is the provisioning of an experimental multi-site test bed. This test bed is created as part of a non-funded extension of the PSIRP project until September 2010. Until this time, several partner sites will be inter-connected over the public Internet to demonstrate certain parts of the PSIRP technology and abilities. In the following, we give a brief overview of the test bed and its intended usage.

Test Bed Set-up

The test bed utilizes the current node implementation [D3.5], i.e., the Blackhawk implementation. Several nodes, depending on availability of hardware, are installed at various partner sites. These local nodes are directly connected through Ethernet. Each local site is interconnected with other sites through an openVPN configuration, i.e., Ethernet frames are tunneled via the public Internet. This will also allow for public demonstration through laptop setups, i.e., a local demo (with one or more laptops) can be connected to the overall setup, assuming that proper openVPN configuration and authorization is in place. The openVPN server is currently located at the University of Essex.

Initially, the different sites are administered as a single PSIRP domain with a single topology manager [D2.4]. Eventually, however, each site will be configured as a single PSIRP domain to fully enable inter-domain operations. Also flexible rendezvous configuration will be implemented, based on the current rendezvous point implementation.

The currently envisioned setup for the test bed until the end of September is:

- Essex University (non-PSIRP partner): 5 PSIRP nodes, acting as publishers and/or subscribers as well as forwarding nodes
- British Telecom Research: 1 PSIRP node
- Cambridge University: 2 PSIRP nodes
- Institute for Parallel Processing – Bulgarian Academy of Sciences: One powerful server with possibility to hold many virtual machines + two more dedicated machines
- Aachen RWTH University: up to tens of PSIRP nodes through cluster machine setup
- Athens University of Economics and Business: several dedicated machines
- Helsinki University of Technology: several dedicated machines

Figure 1 shows a simplified network graph of the testbed.

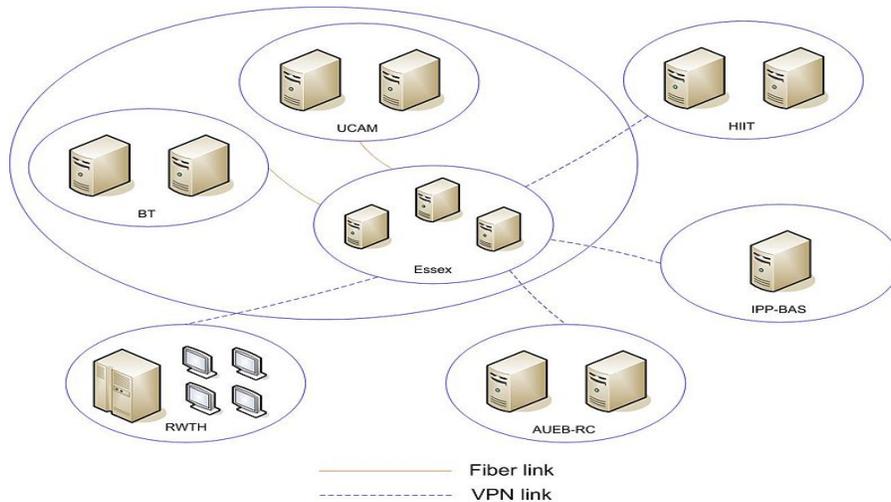


Fig. 1 – PSIRP test bed setup

With this initial setup, in the order of ten or more distributed machines are participating in the testbed, with additional cluster capabilities for virtual machines. As an additional site, discussions are ongoing with MIT to setup at least one or two machines as a PSIRP domain in the US.

Furthermore, at least Essex University and Aachen-RWTH University have expressed an interest to setup forwarding nodes based on the existing NetFPGA implementation for the Bloom filter forwarding approach [LIPSIN].

More specific detail on test bed setup can be found in, e.g., D3.5 and the final technical report on the test bed setup (which is planned for September 2010).

Currently, the following usage is envisioned for the growing test bed:

- **Testing:** components will be increasingly integrated and tested in a real-life environment. Results from this testing will directly feed into the community process for our open source software.
- **Evaluation:** apart from implementation testing, evaluation of technologies is the second usage for our test bed. This includes, e.g., evaluation of the rendezvous and/or forwarding solutions being developed. Other areas are future solutions for topology formation and other rendezvous solutions. We intend to combine this ability for evaluation through emulation techniques, e.g., utilizing the cluster computer abilities of Aachen-RWTH University
- **Demonstration:** apart from individual demos, e.g., during engagement or within partner organizations, the project has submitted an application to the upcoming ICT 2010 event for demonstration of the test bed. We also plan to submit a demo application to the SIGCOMM 2010 conference
- **Engagement:** a particular aspect of demonstration is that of engagement with other efforts or interests. This may include, e.g., engagement with other European or international research efforts, e.g., the UK-funded PAL project which partially utilizes the facilities in the UK.
- **Education:** course work has been developed at HIIT to include pub/sub technology into the future curriculum. The test bed is intended to deepen this educational character by providing hands-on experience with the technologies being discussed during the courses and allowing for application development on a real-life test bed.

The following applications are envisioned (without any guarantee that all of them will be realized):

- Simple file transfer
- Non-realtime video streaming
- Collaborative working (e.g., shared applications)
- Legacy applications through a socket emulator
- Web applications with modifications on the HTTP model.

5 Project Web site and open-source code releases

Public deliverables, a technical report and publications together with general information about the project, including the project presentation, are available in the publicly accessible project web site: <http://www.psirp.org/>.

The Blackhawk pub/sub prototype source code is published under the GPLv2 and BSD open source licenses, so that users and developers of the code can choose which one of these licenses they want to apply. The code with related documentation is available to public in <http://wiki.hiit.fi/display/psirpcode/Home>.

On the community's mailing list (psirp-code@hiit.fi), people from both inside and outside the PSIRP project can ask questions, provide assistance to each other, and discuss about development issues, among other things.

6 Conclusions

The areas explored in the context of this project have already found their way into a number graduate and undergraduate curricula and several MSc and PhD thesis works are ongoing. The released open source code of the project has been taken in use in related EU and national research projects. The PSIRP architecture provides a long-term view of the necessary communication architecture for various data sources like email to ambient sensing, which is evidenced by the fact that the architecture has been adopted by the UK-funded project PAL which focuses on health care. We are confident that the collaboration efforts with other research projects are likely to result in similar success stories in the future as well. The use of the developed architecture looks promising also beyond the traditional communication business; especially Retail, Content-Centric and Government sectors are likely to benefit from information centrality.

Demonstrating capabilities of a new technology in a real-life experiment is a powerful tool for dissemination. For this reason, PSIRP has asked for extending the project to establish a multi-site test bed facility with the currently available technology within the project. The current expectation is that the test bed will be available by the end of the project (September 2010) with demonstration and testing ability. Such ability will be directly transferred into the continuation efforts of the PURSUIT project.

References

- [FIPO] <ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/netmedia/20090507-position-paper-future-internet-architecture-with-disclaimer_en.pdf>
- [D2.4] M. Ain (ed.), PSIRP Deliverable D2.4: Update on the Architecture and Report on Security Analysis, 2009
- [D3.5] P. Jokela (ed.), PSIRP Deliverable D3.5: Final description and evaluation implemented components: including open source deliveries, April 2010
- [D4.6] Final Evaluation Report on deployment incentives and Business Models, 2010 (to be finalized).
- [D5.3] H. Flinck (ed.), PSIRP Deliverable 5.3: Dissemination Report, 2008
- [D5.4] H. Flinck (ed.), PSIRP Deliverable 5.4: Dissemination and Exploitation Report, 2009
- [IT] L. Maxwell, It's ours; why we, not government, must own our data, Centre for Policy Studies, http://www.cps.org.uk/cps_catalog/it's%20ours.pdf, 2009
- [LIPSIN] P. Jokela & al., LIPSIN: Line speed Publish/Subscribe Inter-Networking. SIGCOMM'09, <http://conferences.sigcomm.org/sigcomm/2009/> Aug 20, 2009.
- [MIT] Identity in an Information-centric Internet, http://cfp.mit.edu/CFP_Papers/Identity%20Whitepaper%20v13_clean-3.pdf
- [MPSS] A. Zahemszky & al., MPSS: Multiprotocol Stateless Switching,, in proceedings of 13th IEEE Global Internet Symposium 2010, San Diego, CA, USA, March 19, 2010.