THE BUSINESS VALUE OF INHERENT NETWORK MANAGEMENT APPROACHES FOR THE FUTURE INTERNET

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ABSTRACT

Today, the management of broadband access networks is usually centralized with simple support functions in the network elements for monitoring and triggering alarms in failure cases. The future Internet will connect heterogeneous parts for different fixed, wireless and mobile transmission technologies, as well as overlays on network and service layers (e.g. VPN-, P2P-based) with new challenges and opportunities for network management.

In the framework of the EU funded 4WARD project we are currently studying new management concept based on autonomous, self-organising entities with more inherent management capabilities (INM) in the network nodes. In this way, the reliability and scalability of centralized management can be improved, and completely distributed management concepts are investigated, e.g. for dynamic network environments where centralized approaches fail. In this paper, we study the INM business value in a qualitative analysis by describing scenarios where INM is expected to improve performance and save costs.

1 INTRODUCTION: MANAGEMENT OF THE FUTURE INTERNET

Fixed and mobile broadband access is developing towards a standard for business and residential home users with more and more attractive services being integrated on Internet platforms. The corresponding cost and business models cover multiple layers from infrastructure to service provisioning. New Internet services continuously create new revenue opportunities in online markets, while network operators can profit from an increasing subscriber base attracted by a steadily extending service spectrum. They facilitate the launch of new services and in addition help to reduce the effort and costs of service and network provisioning.

The INM paradigm presented by the 4WARD project allows for an integrated approach to service and network management while embedding intelligence into the network and minimizing the requirements for human intervention.

Since a quantitative prediction of the INM business value for developing new services seems speculative, we focus on describing main cost saving effects through INM for operational (OpEx) and capital (CapEx) expenditure. Diving forces of the expected savings and business support can be seen in

- Self-organization and automated processing, reducing the need for manual intervention in current network operation
- Distributed monitoring and control for better situation awareness, resulting in faster and more precise proactive and repair processes
- Virtualization concepts which include autonomous management in a common framework
- Improved control and reporting functions for business management

Savings in CapEx are expected through combined situation awareness and optimization allowing for more efficient network resource usage [14]. Since current preferences for overprovisioned networks also contribute to wastage of energy in underutilized electronic equipment, optimized resource management supports CapEx saving together with a trend to green information and communication technology (ICT).

We summarize OpEx and CapEx aspects in network management from a general point of view in section 2, while section 3 addresses main contributions and shifts to be expected from autonomous and self-organising approaches. Profitable scenarios for those approaches with focus on dynamic networking and overlays are discussed in section 4 followed by the conclusions.

2 RELEVANT CATEGORIES IN OPEX AND CAPEX

Operational (OpEx) and capital (CapEx) expenditures are interconnected issues [18]. It depends on the network environment whether OpEx or CapEx represents the major portion of the overall costs of the network and service provisioning [3][9]. In a Future Internet environment, automated technologies and functions to facilitate management tasks may initially shift costs from OpEx to CapEx but in the long term will reduce the total costs as simplifying standard solutions. The level of achievable self-organization is different in fixed backbone and access network types, as compared to wireless and mobile networks.

Network layers are another criterion for differentiation. Virtualization concepts can provide a completely self-organizing environment for some task on top of a physical network infrastructure. Developments towards virtual concepts can already be seen in application layer overlays, e.g. peer-to-peer networking, whose economic aspects are the main topic of the EU project SmoothIT <www.smoothit.org>.

In this article, we focus on processes in operational networks. Therefore first installation costs in OpEx as well as CapEx for setting up a network, buying equipment etc. corresponding to processes defined in [16] are not considered. We assume that the same categories of operational processes will be as relevant in Future Internet as they are in today's networks. However, the way these processes are designed and implemented will make the difference in a Future Internet scenario. The costs occurring in an operational network can be divided into the following categories related to main management tasks and processes:

1. Continuation of normal network operation
   The cost to keep the network running in a failure free situation including space, power supply, leasing equipment, e.g. fiber rental etc

2. Maintenance and monitoring
   The cost to maintain the network and to operate the network with awareness of failure events based on monitoring of the network and its services

3. Failure handling and recovery
   Failures in the network have to be repaired on a case by case basis triggered by alarms, if this cannot happen in routine operation. Reparation may lead to actual service interrupts depending on the protection scheme.

4. Planning and updating of an operational network
   This category includes all planning performed in an existing network which is up and running, resulting in long term upgrade processes for increasing traffic and resource demands as well as short term workarounds and (re-)optimization, upgrades or replacement of outdated software and hardware components.

5. Service management and provisioning
   Processes set up to provide and control previously negotiated services to customers, usually defined via service level agreements (SLA)

6. Business management, marketing, pricing, sales
   Business and service managers govern the network to support a service portfolio through a set of business decision processes. They use policies at the top level when developing new end-user services.

Network management has direct influence on the first four categories and interacts with service and business management through predefined interfaces and processes. Studies on the distribution of OpEx for network operators [9][15] attribute roughly 27% to marketing and sales, 24% to customer and IT support services, 22% to network elements and another 27% to interconnection and roaming.

Table 1 shows that the latter portion has higher estimates for mobile and lower for fixed operators. Interconnection costs also differ with the size of network and Internet service providers (ISPs). Globally operating tier-1 ISPs often provide Internet connectivity for smaller ISPs but can profit from peering contracts with them.

OpEx Category	Estimate for mobile operators (GSM) [9]	Estimate for mobile operators [15]	Estimate for fixed operators [15]
Network Elements	20%	20%	25%
Marketing & Sales	26%	26%	30%
Customer Service	15%	8%	10%
IT Support & Service	13%	11%	15%
Interconnection, Roaming	26%	35%	20%

Table 1: OpEx distribution estimates

3 THE IMPACT OF INHERENT NETWORK (INM) MANAGENT ON BUSINESS VALUE

Basic concepts of the INM approach are decentralization, self-organization, embedding of functionality and autonomy, as illustrated in Figure 1. This enables management tasks or subtasks to be delegated from special management platforms to a self-organizing management plane inside the network. At least an appropriately selected part of management functions can be perform inherent to the network, for instance, reconfiguration or self-healing in an autonomic manner.

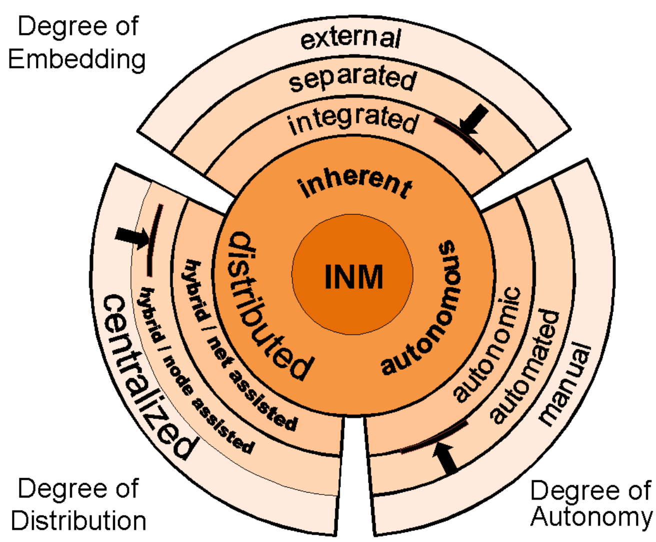

Figure 1: Developments towards INM

Real-time monitoring or, more general, situation awareness, for several reasons. First, monitoring, i.e., the process of acquiring state information from the network and its nodes, is a fundamental precondition to operate a system efficiently. Monitoring functionality is generic since it can directly support the management of the underlying concepts being developed within EU project 4WARD [2], i.e., network virtualization, generic paths and network of information.

3.1 OpEx reduction through self-managing instances

In nowadays heterogeneous networking environment, different domains establish their own degree of embedding, autonomy and abstraction, depending on the technology, applications and administrative goals. Wherever a higher autonomy level or more flexible adaptation is achieved, expenses for manual intervention are reduced with consequences for OpEx [1][12].

Centralized management in large scale networks is often subject to uncontrolled floods of alarms being forwarded to the network operation center in failure cases. Self-managing entities in INM are expected to enforce efficient local control loops which can filter and forward more consolidated reports instead of spontaneous data records. INM can aggregate control messages within entire sites and areas. It will not be necessary to have every network element connected to a central network management system, which may detract from scalability on large platforms. While this can reduce overhead and facilitate failure analysis in large scale networks, it is a precondition for deploying small home or building networks, which have to work in an autonomic manner without an operator being involved and otherwise have to generate failure reports to be understood by untrained people.

3.2 CapEx reduction through situation awareness and fast adaptability

Giving preference to a higher autonomy level, self-organizing schemes can also profit from ICT technology trends towards steadily improving performance. As a side effect of increasing bandwidth, monitoring and control cycles can be executed at higher frequency, resulting in immediate and more precise situation awareness for distributed network functions [14]. Consequently, resource optimization, load balancing and rerouting can adapt to traffic shifts and prospective failure scenarios in shorter response time, which makes them more reliable and robust.

As an example, we consider traffic engineering on broadband access platforms, which has to cope with link upgrading processes for increasing Internet traffic and has to take care of failure situations by providing backup paths [5][8].

(G-)MPLS or Ethernet with multiple spanning trees are technologies that allow to establish load-balancing traffic paths. They can be pre-computed, not only for the current topology and traffic load, but also for modified topologies to upgrade link bandwidth and to include relevant failure scenarios. In the latter case it is still time critical to reconfigure the paths to circumvent a failed link in an operational network. Therefore additional capacity is usually provisioned to overcome non-optimized intermediate stages after topology changes due to failures or upgrades.

INM functionalities for faster situation awareness and adaptability through automated online processes can reduce those time gaps subject to unbalanced or instable load in the network and, as a consequence, allow for reduced over-provisioning for such situations. Experience with traffic engineering in IP backbones [5][8] has shown that a 20%-30% increase in utilization – or a corresponding decrease in provisioned bandwidth of IP routers and transmission equipment – is possible when the network can be kept in optimized load-balanced regime by fast redirection of transport paths from overloaded resources.

3.3 Support for business and service management

Business and service management relies on and interacts with network management, e.g. for evaluation of the network status and performance over time. Advanced INM monitoring and automated reporting again improve the timeliness and precision of evaluated data and support SLA fulfillment etc.

As a long-term vision, self-adaptation and autonomous management may vertically integrate network resource monitoring, planning, administrative policies with business and market strategies. For example, pricing for access and IP services may be made dependent on temporary bottlenecks and restricted scalability of network resources. In the opposite way, marketing campaigns and new pricing for web services may automatically trigger support actions in resource provisioning and management for prospective shifts in demand.

4 Scenarios and case studies

4.1 The need for inherent network management in dynamic networks

Besides the mass market of broadband access platforms, a Future Internet also will integrate sensor, mobile ad hoc and overlay networks which are subject to changes in the topology on short time scales. A high level of dynamics makes it challenging to keep an up-to-date view of the network topology. As a consequence, routing tables and the network status information in centralized management systems are becoming imprecise and more or less invalid.

Thus, dynamic network environments represent an area where classical management and routing concepts fail and a clean slate approach seems indispensable [12]. The IETF has set up a working group on ROuting over Low power and Lossy networks (ROLL, www.ietf.org/html.charters/roll-charter.html) to study whether existing protocols can be adapted or what new methods have to be set up for networks with unreliable nodes and links.

Network management has to be included as a next step [12] [19]. Therefore concepts of inherent network management (INM) are relevant to achieve fast local situation awareness and control, which can be exchanged and evaluated in larger domains via distributed and gossip-based algorithms [9][20], random walks [7] or reinforced learning [12]. The scope of dynamic networks covers heterogeneous environments e.g. for home, building and urban networks or communication for recovery from catastrophes and military applications. When new concepts can be realized to manage and operate networks with a high level of dynamics, they should be flexible to handle less dynamic scenarios and to support a centralized view of the network as far as possible.

INM may contribute in a long term perspective to a generalized network management framework spanning a wide range from distributed architectures for dynamic systems to centralized schemes for stable topologies [16][17]. In this way migration steps towards self-organizing and autonomous components are also prepared for classical management areas.

4.2 INM for Femto-cell networks

The growing field of femto networks presents an interesting area to which the INM principles lend themselves or could at least be studied within. The way they are designed, in combination with the femto characteristics make them a promising candidate for evaluating INM designs. Since femto cells combine fixed and mobile networks, they are right at the heart of convergence. A usual scenario is shown in Figure 2.

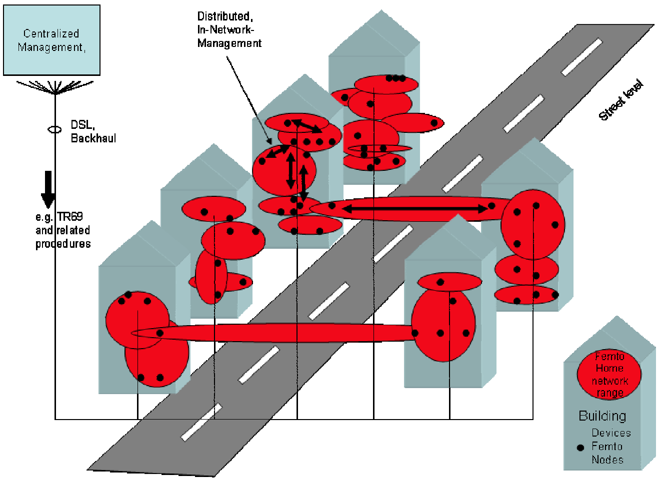

Figure 2: Femto-cell network example with relation to INM

Additionally, they implement a potentially vast area of the Internet's network edge, including end user's homes. What makes them even more special is the fact that they are designed in a way that requires a comparatively very low administrative, management and also planning effort – and this is part of the business case behind, which, of course, mostly builds on spectrum economics. However, there is a potential for improvement, which is two-fold:

- Femto-designs often use a so-called femto-access-gateway, a centralized network element coordinating network access for femto installations. We assume that parts of this functionality could be executed "inside" the femto-cloud such that less capacity is needed on the gateway.
- Since there is almost no spectrum management for femtos, there are obvious options for improving, for example, anti-interference management, which would be implemented according to the INM principles, i.e. mainly by letting femto nodes communicate and negotiate with each other. While currently TR-69-like standards describe the centralized management, this could be complemented by an INM inter-femto signaling and management protocol.

All in all, we believe that femto-cell networks, in particular the upcoming, LTE (flat architecture) based femtos, are good candidates for evaluating INM concepts. The business value can be modeled according to both presented improvement options. If the INM principles can be validated and assured in combination with cost or capital expenditure savings for the femto application, it should be evaluated for other scenarios, too, such as MPLS based core networks, for example.

4.3 Inaccuracy in situation awareness: A standard OLSR case study in MANETs

In a case study we focus on using the optimized link state routing (OLSR, RFC 3626, <www.ietf.org/rfc/rfc3626.txt>) as the standard routing protocol of the IETF MANET working group to be extended for situation awareness. We consider wireless broadcasting nodes placed at different locations spread over an area, initially without mobility. We assume that two nodes can directly exchange messages when their distance does not exceed a common transmission range. In this way, the transmission links between nodes and the network topology is determined by the node locations.

The nodes route messages via OLSR over multiple hops, including Hello and topology control (TC) messages at default intervals of 2 and 5 seconds, respectively. We consider the queue size of messages that arrived at a node but are not yet forwarded towards the destination as a quality of service (QoS) measure. OLSR is extended to distribute the queue size such that each node is aware of the queue size at all other nodes subject to a delay until routing updates are received between nodes. The queue size information is not used for load balancing. To store the QoS-related state associated with a node, a new field is added to the neighbourhood information base and to the topology information base maintained by the protocol. To populate these fields, the message format of Hello and TC messages were extended as well. Table 2 summarizes the parameters of the modeling and simulation parameters.

Simulator Parameters	
Network Type	IEEE 802.11
Propagation model	Two-Ray-Ground
Mobility model	Static
Transmission range	250 m
Network topology	50 nodes randomly located in 1 km^2
Traffic model	20 random source-destination pairs, constant messaging intervals: 0.2s, 0.14s, 0.09s, 0.04s, 0.02s for different traffic load levels
Packet size	128 Byte
Queue	for max. 50 packets; Tail-Drop
Simulation time	200s; 50s start phase not evaluated

Table 2: Simulation Parameters

In this scenario, we study the absolute difference between the current queue size at a node and the aged information about it, which is available at the other nodes through routing messages at the same time, as a measure for inaccuracy of the routing information state.

Figure 3 combines the evaluation of deviations in queue size information with the age of the information at the nodes. The *k*-th column gives the mean deviation for nodes whose information is aged between *k*-1 and *k* seconds or is larger than 21s in the last column.

As can be expected, the deviation is essentially increasing with the traffic load, which varies for the five curves by a factor of 10 from low and medium load up to congestion. Inaccuracy is also increasing with knowledge age, although not monotonically and partly even decreasing for the low load curves. This effect is due to the fact that the paths of messages utilize nodes in the middle of the square area more often than nodes in the outer regions. Thus the nodes in the middle experience higher load and queue variability. But the knowledge age about nodes in the outer regions is larger, while they have a low and less variable queue size. This trade-off causes a tendency to decrease the inaccuracy in spite of larger knowledge age, which becomes apparent especially for the low traffic curves.

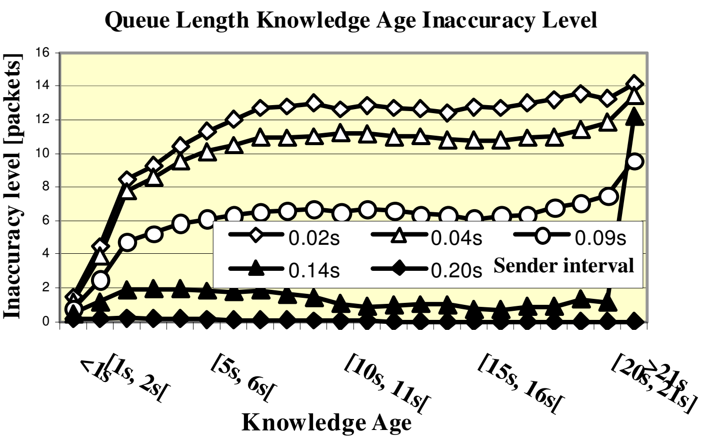

Figure 3: Inaccuracy in routing data and situation awareness

We also analyzed the impact of sending more frequent Hello and TC messages but did not obtain a positive impact on the overall inaccuracy level. In order to reduce knowledge age, we enhanced the routing by a probing scheme. The current state of a node is looked up by a probing message which is triggered by a threshold for the age of information. Probe messages are fully exploited by updating the new status information for all nodes on their paths as well as for nodes which receive the information due to broadcasting in the surrounding of the path.

The probing scheme was able to halve the mean knowledge age from about 10s to 5s, but in spite of the improvement in knowledge age, probing was unable to reduce the inaccuracy in the queue size estimates. Again, this can be explained from the results in Figure 3, since the inaccuracy level stays almost constant for knowledge ages of 5 and more. Only for ages below 3 seconds essential improvements of the accuracy are observed.

This study for fixed randomly chosen topologies shows that the overall inaccuracy of routing and management information can be high in wireless multi-hop communication. In addition, mobility or high churn will affect reliable transport of routing messages and will increase inaccuracy due to route flapping and loops.

When high dynamics impedes convergence of link state and distance vector routing protocols, then flooding and random walks can be used as well as methods combining flooding, random walks with partial routing knowledge [7].

4.4 Remarks on further dynamic and overlay management scenarios

Peer-to-peer and sensor networks represent important dynamic network scenarios. Due to the demand for cheap sensors with limited battery power, nodes are often put into a sleep modus, leaving a dynamically changing set of active nodes in normal operation.

The dynamics in peer-to-peer networks is caused by peers going online and offline spontaneously. For both, sensor and peer-to-peer networks mobile nodes can again add to dynamics. Peer-to-peer networks have developed their own autonomous and distributed management functions on the application layer, which are partly highly efficient, e.g. with regard to replication of data, reliability and throughput [9]. They rely on the network layer for providing basic connectivity between the peers and in this way they are outsourcing main parts of the management as it may also be done in virtualized networks via generalized concepts for the interfaces between virtual frameworks and the network infrastructure.

On the other, peer-to-peer networks are currently subject to cross-layer inefficiencies, leading to unnecessary long transmission paths between peers instead of e.g. preferring sources in the near of a downloader. Many other management functions that enhance for broadband access platforms are not used in peer-to-peer overlays, from registration and accounting of users to monitoring of the utilization and performance of resources.

CONCLUSIONS

Although centralized management approaches are expected to persist in fixed broadband access platforms in near future, autonomic and decentralized approaches will develop in dynamic network domains which currently are becoming more important in several areas including MANETs, sensor networks, overlays and virtual network environments.

When inherent management solutions successfully establish in dynamic networks where central management isn't applicable then self-organizing entities and functions can be transferred to areas under central control. In this way, central management functionality is not expected to be replaced, but to be enhanced by local control, filtering and aggregation of monitoring data and alarms for improved reliability and scalability.

The implementation and evaluation of further scenarios requiring INM concepts in the future Internet is currently under study by the EU 4WARD project team.

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