



# WIRELESS WORLD

## RESEARCH FORUM

### Madeira: A peer-to-peer approach to network management

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**Abstract**— Current management approaches like the Telecommunications Management Network are based on a hierarchical structure and use rigid interoperability standards that make them less applicable to dynamic, heterogeneous network environments. This paper will give an overview of the innovative Madeira management solution, which is based on distributed, peer-to-peer principles.

Madeira provides novel technologies for a logically meshed Network Management System that facilitates self-management and dynamic behaviour of nodes within the network. It performs network management tasks that are difficult to carry out using conventional methods, or tasks that can be carried out more efficiently using a distributed approach. The focus of Madeira lies on Configuration and Fault Management, and the collaboration between these two functional areas.

The management functions are executed in peer-to-peer aware Adaptive Management Components, or AMCs. By using the peer-to-peer interface, these AMCs interact with each other and create an Overlay Management Network in order to perform specific management tasks. The behaviour of the management application is influenced by the use of policies. To ensure the scalability of the network, the nodes are grouped into Management Clusters. Each cluster has a Cluster Head that is responsible for the coordination and topology publishing of its cluster.

Madeira also offers support for a higher layer Operation Support System, or OSS. It can issue alarms containing meaningful information for the operator, publish the complete network topology and receive management commands from this external OSS.

In order to demonstrate the capabilities and strengths of the Madeira management approach, a number of scenarios are included

that describe real life problems that occur in WiFi networks, and that are difficult to solve with the traditional management approach.

**Index Terms**—network management, peer-to-peer, self management, wireless meshed networks

#### INTRODUCTION

TELECOMMUNICATION networks are getting larger and more heterogeneous. These large, transient next-generation networks have a great need for automated network management in order to reduce operating expenses (OPEX). The global adoption of IP-based networking solutions since the mid-1990's and the recent emergence of the Internet as the platform for next generation services has highlighted the need for a powerful management technology and for an overall framework for the automated management of emerging networking infrastructures. Broadband access technologies in particular have started to act as a catalyst for the radical substitution of public switched telephone services with Voice over IP (VoIP) while optical switching technologies have started to be deployed both in the access and core network. Furthermore, wireless communication has been gaining ground in the last few years. Besides the extensive growth of mobile telephony, also WiFi networking is becoming more and more popular. The emerging environments will have new and more sophisticated management requirements, similar to those of telecommunication networks.

In the above context, the use of traditional, hierarchical management techniques suffers

a number of disadvantages like static architectures and rigid standards, which make them less suitable for these large and dynamic environments. Initial and well established frameworks in the telcos networks such as the OSI System Management (OSI-SM), using the Common Management Information Protocol (CMIS/CMIP), were management-specific approaches adopting the manager-agent model. This is the foundation of the Telecommunications Management Network (TMN), which was defined by ITU-T as a framework for the management of communications networks in ITU-T M.3000 recommendation series. In the mid-1990's general distributed object technologies (DOTs) emerged, with the Common Object Request Broker Architecture (CORBA) being the most representative one, spurring a lot of research and standardization activities regarding their use for management. Since then, OSI-SM has been confined to telecommunication environments for network management purposes while CORBA and Java-based distributed object technologies have been used for service management.

A next generation management technology is required, together with an overall framework for network-wide optimal configuration according to well-defined goals and constraints. Approaches based on network programming, management overlays, peer-to-peer (P2P) computing, as well as distributed aggregation and control schemes, have been recently proposed to engineer management systems with good scalability behaviour and that are robust regarding topology changes and failures.

This paper presents a solution to overcome the drawbacks of present day management approaches; the solution developed in the Madeira project. Madeira is based on peer-to-peer technologies for a logically meshed Network Management System that facilitates self-management and dynamic behaviour of nodes within the network. After this introduction we present a section devoted to the highlights of current and state of the art solutions for network management systems. This serves as a framework to understand the impact of our proposal. After a short introduction on the Madeira management approach we present the details of our architecture. This is followed by the scenarios that will be used for evaluation during next months. Finally we end with some concluding remarks.

## Current Network Management Approaches and Trends

### Management Frameworks

In the past years, TMN has been the dominant network management framework. It promotes a well known centralized approach [19] which has a number of effects on the scalability of the network management application. Managing a large network from a single, central point will increase the load of the central manager and could create bandwidth bottlenecks on links that are close to that central manager [6].

Another disadvantage is the lack of flexibility, since the current generation of management architectures use static topology data, often based on manually generated files. This complicates reconfiguration of a dynamically changing network. Changes in the topology are normally implemented from the top of the management pyramid, and pushed down into the network. Fault Management is often based on the same static topology that is saved in the management system. For example, Alarm Correlation normally assumes a static topology, while in meshed networks this topology is dynamic and time-based.

TMN is divided into five layers, depicted in the pyramid in Fig. 1 [19]:

- Business Management takes care of the management of the whole enterprise. It can be seen as goal setting rather than goal achieving.
- Service Management is in charge of managing aspects that are directly observed by the users of the telecommunication network. It addresses topics like customer care, service development and operation, Quality of Service management, accounting, etc.
- Network Management provides management services that are related to the interaction between multiple pieces of equipment.
- Element Management takes care of vendor specific management functions which are hidden from the Network Management layer above. For example, it can detect equipment errors and perform measurements on temperature and resource usage.
- Network Element provides agent services, mapping the physical aspects of the equipment to the TMN framework.

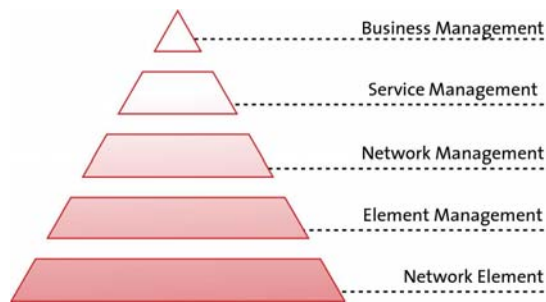


Fig. 1: TMN Pyramid

As an evolution of TMN, the TeleManagement Forum, or TMF, proposed the Telecom Operation Map [26] and, more recently, the eTOM. These models describe at a high level the processes a telecom operator needs to fulfil to manage its network and services infrastructure. Furthermore, TMF has defined the NGOSS architecture, which is a technology agnostic framework for the construction of management applications. NGOSS fosters a component based architecture with interfaces between components defined as contracts, a shared information model and the separation of implementation from business logic [9], [25].

An interesting implementation of NGOSS concepts is OSS/J which pursues the implementation of a set of APIs, based on J2EE technologies, to allow the integration of OSSs [16].

It is also worth mentioning the 3GPP approach to network management, which is based on the IRP (Integration Reference Point) concept. The IRP is analogous to the TMN Q3 reference point, improving it by defining the information models in an implementation independent UML.

An important assumption behind TMN and similar frameworks is that network elements have limited management capabilities, being focused on their communications role. Therefore, management functions are performed externally by dedicated systems, while network elements only provide simple management agents to allow these external systems access and manipulate management data. It was recognised considerable time ago, however, that network devices can do much more than running a simple agent, being even capable of managing themselves [28]. This is the approach taken in IP networks, where nodes are able to perform management tasks for routing, signalling, path provisioning, etc.

Following this trend, the control plane paradigm has emerged in telecom networks, giving more autonomy to network elements for certain tasks. Particularly in optical networks, research is being conducted to create an optical control plane that enables automated multi-vendor network operation. Examples are the ITU's Architecture for Automatically Switched Optical Networks (ASON) and the IETF's Generalized Multi-Protocol Label Switching (GMPLS) [5]. However, decentralized standards are not (yet) available for wireless networks.

Note that the existence of a control plane does not mean that the management plane is no longer necessary, but rather that it must adapt to the new scenario, focusing on the tasks for which it is better suited and relying on the control plane for other tasks such as routing and signalling [1].

## Distributed Technologies

One of the main problems faced by the network and service management field is the integration of different platforms and applications [7]. Distributed technologies and frameworks have greatly helped to solve this problem, avoiding the need for dedicated or proprietary protocols.

The distributed system management approach with the most impact has undoubtedly been the introduction of the Object Management Group (OMG) Common Object Request Broker Architecture (CORBA). Reasons for using CORBA in TMN environments are that OSI management system was conceived as an object-oriented management technology in the absence of a distributed object-oriented framework. CORBA provides exactly such a framework, with a superior distribution paradigm in which every object could be potentially distributed [14]. Moreover, the performance could also be better than OSI management due to a more lightweight protocol stack than the conventional CMIS/CMIP.

The use of CORBA has been proven valuable in managing several network technologies as in the challenging area of IP and WDM network integration [20] and has also deserved the attention of the standardization bodies. Nevertheless, the use of CORBA is not exempt of disadvantages. In fact, the OSI object management model is more expressive and the mechanism for accessing objects is superior thanks to the incorporated scoping

and filtering concepts. Finally, a distribution mechanism of pre-filtered events makes it appropriate to deal with alarm and event notifications. For these reasons, the idea was to keep the OSI management model and tools for Element Management and Network Management whilst using CORBA for the upper layers of the TMN pyramid. But the coexistence of both models poses serious compatibility challenges addressed by several authors [17].

Web Services [27] is an emerging Internet-oriented technology that has strong analogies to CORBA. Although in principle not conceived for that purpose it is clear that due to this analogy it could also be used for network management. Currently, research on the use of Web Services for network management is being conducted by organizations as OASIS. Originally, Web Services were stateless entities. The OASIS Web Services Resource Framework [13] solves this problem by defining a framework for stateful resources. Besides, OASIS defined the Web Services Notification standard allowing the usage of a publish-subscribe communication pattern. Among others, these two standards have been used in the Management Using Web Services specification, which is part of the OASIS Web Services Distributed Management Technical Committee [11]. It enables the management of distributed resources. Although these solutions are very promising, it remains important to consider aspects pertinent to Web Services (XML encoding overhead, etc.). In that respect, the fact that Web Services is an XML-based technologies makes it very attractive due to its potential easy integration with other applications but this also causes the drawback of higher overheads than CORBA.

Another approach to decentralized network management tasks is the usage of Mobile Agents, which are small software programs that 'travel' through the network. These agents decentralize processing and control by remotely performing certain management tasks [2], but the security requirements on the execution environment are extensive, resulting in performance and functional limitations as indicated in [22].

### **Peer-to-Peer**

P2P systems, which have proven to be highly scalable and robust, can be utilised to establish service specific management

overlays. Making management information available via such overlay networks has great advantages since it avoids dedicated management systems and supports fast deployment of new services together with their effective management. According to [3], peer-to-peer systems can be characterized as distributed systems in which all nodes have identical capabilities and responsibilities and all communication is symmetric. In [23], Schollmeier indicated that some define peer-to-peer networks as a collection of heterogeneous distributed resources which are connected by a network, while others define it simply as the opposite of Client/Server architectures.

In a P2P system, the nodes have a significant or total degree of autonomy from central servers. As pointed out by [24], P2P systems enable the utilization of previously unused resources as storage, cycles or content for example, by tolerating and working with the variable connectivity of numerous devices.

An overall characteristic of a peer-to-peer network is that the nodes can send and receive information in a way that makes them both servers and clients, or 'servents'. In both [23] and [8], a distinction is made between pure peer-to-peer networks and hybrid peer-to-peer networks, as described below.

- Pure P2P architectures are completely decentralized. There is no central server or router. Each node can issue and respond to requests, or route requests to other nodes.
- In Hybrid P2P architectures, more types of nodes exist. The leaf nodes are nodes with an information need or information resource. In other words, they can provide information to or request information from other leaf nodes. Another type of nodes, super peers, have a more 'server-like' role in the network. These nodes provide regionally centralized services to the network in order to improve the routing of information requests. In [8], these nodes are called directory nodes or ultrapeers. Each directory node provides directory services for portions of the network and directory nodes work in a cooperative manner to cover the whole network.

Fig. 2 gives an example of both types of peer-to-peer networks. A node marked with the letter 'S' represents a super peer.

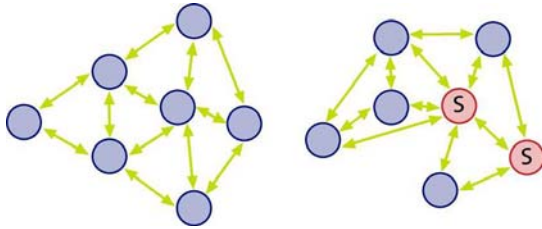


Fig. 2: Pure peer-to-peer (left) and hybrid peer-to-peer (right)

## The Network Management Approach in Madeira

In an attempt to overcome the shortcomings of the traditional management approaches to face the challenges of next generation telecommunication networks, Madeira aims to develop a new management framework based on peer-to-peer networking concepts. Furthermore, it provides novel technologies for a logically meshed Network Management System that facilitates self-management and dynamic behaviour of nodes within the network. Madeira also takes advantage of the Policy Based Management Paradigm [21] that pursues the separation of management logic from the actual applications. This logic is then specified as a set of rules or policies that can be dynamically fed into the management system allowing a change of its behaviour without the need of changing the application or even restarting it. Besides the innovative architectural framework, the Madeira project will provide interface protocols, standards and a reference software implementation and apply it to a specific network management scenario. Ultimately, by enabling the management of network elements of increasing numbers, heterogeneity and transience, the Madeira approach should reduce the Operational Expenses, or OPEX [29].

Madeira focuses on Fault and Configuration Management functional areas and, especially, on the way they can cooperate to solve management problems. In doing so, it will act as a complement to traditional management systems. There are many management tasks that current network management systems perform well such as Performance Management. For these tasks, a hierarchical approach is entirely appropriate. Madeira will investigate the feasibility of distributing management responsibilities among peer nodes in order to perform certain tasks more efficiently. In other words, the Madeira management

approach is applied to management tasks that are difficult to carry out using conventional methods, or tasks that can be carried out more efficiently using a distributed approach.

## The Architecture AMCs and the Overlay Management Network

The approach of Madeira is completely different than in traditional management systems. It encompasses a much flatter structure that is based on peer-to-peer (P2P) principles. The management functions are executed in P2P aware Adaptive Management Components (AMCs), which correspond directly to the Network Elements (NEs). By using a well-defined east-west (or peer-to-peer) interface, these AMCs can communicate with each other, creating an Overlay Management Network. Fig. 3 gives a graphical representation of this overlay.

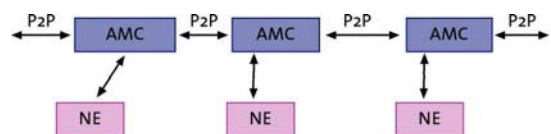


Fig. 3: Overlay Management Network using AMCs

Another basic principle in Madeira is to delegate management functions (and corresponding management information) down to the Network Elements as far as possible. It makes no real difference whether management functionality is residing on the Network Elements themselves or on dedicated Network Management nodes (as has been depicted in Fig. 3). By making use of the east-west interface introduced with the P2P paradigm, both become part of the Overlay Management Network. Such a configuration of AMCs residing on each NE as well as on dedicated Network Management nodes is shown in Fig. 4.

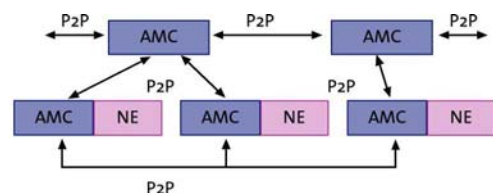
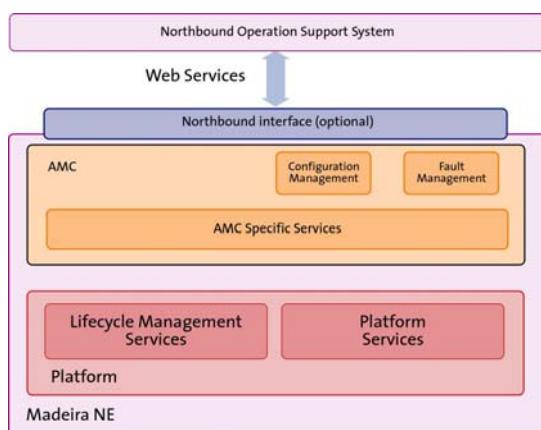


Fig. 4: Overlay Management Network including AMCs on NEs

As mentioned before, an Adaptive Management Component (AMC) fulfils the network management functionality of a peer in a P2P network. It can exchange

management information between peer management applications in a network element or management node. The AMC has the ability to import (and export) functionality to perform specific tasks. One or more AMCs interact with each other to perform a specific network management application.

In order to perform these tasks, an AMC requires an execution environment (a Container) and a variety of services. The Madeira platform provides both of these. The separation of the Madeira Management System between AMC and platform is depicted in Fig. 5. The AMC covers the management specific parts for a particular scenario, while the platform provides all the generic functionality required to run tasks in a P2P environment. This separation of functionality enables Madeira to adapt to changing scenarios and requirements in an efficient way.



**Fig. 5: Layering of services on a Madeira Network Element**

The same Fig. 5 also shows the high-level layering structure on a Madeira Management Network Element. The following groups of services are available in an AMC:

- The Configuration Management and Fault Management layer contains the specific network management applications. They provide the ability to set-up the network, react to faults and other FM and CM related tasks. A description of how these tasks are performed will be described in the section dedicated to the scenario.
- The Northbound Interface is optional. The Northbound Interface offers services which communicate with a higher layer Operation Support System (OSS) via Web Services. The OSS can, for example, retrieve information like network topology, events or alarms. More

information on the connection with an external OSS will be given in the section “Connecting to the North”.

- The AMC Specific Services offers a base for the Network Management Applications. It mainly provides services to communicate with other AMCs. This can be either publish-subscribe based, or a direct peer-to-peer connection to another AMC.

As mentioned before, the AMC performs all tasks that are directly related to network management. To execute these tasks, the AMC needs services that are offered by the platform. The platform takes care of all additional functionality that is needed in a peer-to-peer environment. Its capabilities are divided into two group of services:

- 1 The Lifecycle Management Services take care of the management of AMC containers. In more detail, this group offers the following services:
  - The Lifecycle Service can perform start/stop/restart operations on all modules loaded by the AMC.
  - The Code Distribution Service enables dynamic loading of application logic/data into the AMC. AMCs have a minimum “bootstrap” configuration to function in the network. Additional functionality can be imported as required with this service.
  - The Security Service provides all aspects of security and authentication from a platform perspective.
- 2 The Platform Services offers the following services, which are specific for the peer-to-peer environment:
  - The Notification Service is a basic event notification service, based on a standard publish-subscribe service. It enables AMCs to subscribe to certain event types.
  - The Directory Service is a directory of AMCs with their roles and capabilities. It keeps track of the physical one-hop neighbourhood of the NE and enables AMCs to be looked up
  - The Connectivity Service provides reliable one to one communication between two AMCs. This point to point connection supports multi-hop P2P communication.
  - With the Persistency Service, AMC data can be stored for retrieval across

restarts. It supports permanent storage of application-defined data.

- The Grouping Service can dynamically form AMC groups for a given management function. It provides application partitioning for AMCs of similar roles or capabilities.

Using the AMC as a basis, four different types of interfaces are specified to facilitate communication with components:

1. The Peer-to-Peer interface, to communicate with other AMCs.
2. The Northbound interface, to communicate with another NMS or OSS.
3. The Southbound interface, to access NE application specific functionality.
4. The Interface(s) to the platform, to communicate with Lifecycle Management and Platform Services.

The relation between the AMC and these interfaces is shown in Fig. 6.

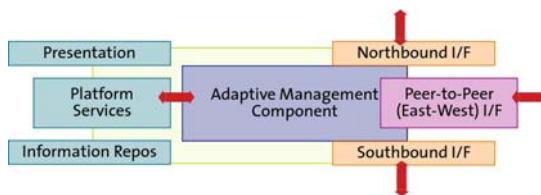


Fig. 6: Four different types of interfaces

## Clustering

The Grouping Service provided by the Platform Services offers the ability to create groups of AMC that perform a specific management function. These groups are called Management Clusters. Each Management Cluster contains exactly one network node that acts as the Cluster Head. This Cluster Head is responsible for coordination of and topology publishing for its cluster. The clustering principle makes Madeira a hybrid peer-to-peer solution, where the Cluster Heads can be seen as “super peers”. The other nodes are “normal peers”, as described before.

Different levels of clustering can exist, which leads to a clustering hierarchy. A node in a level “n” cluster is the Cluster Head in a level “n-1” cluster. The top level Cluster Head is responsible for publishing, for example, the topology of the complete network and events or alarms to a higher layer Operation Support System or another Network Management System. In order to perform this task, the top level Cluster Head will contain the Northbound Interface.

The use of this clustering concept is of

great importance for the scalability of the management application. It creates the ability to divide a large network into smaller, dynamic groups to perform certain management tasks. The scenario described further on will elaborate more on the use of Management Clusters.

## Policies

In Madeira, policies are used to tune the behaviour of the management application. These policies are introduced to the system by the Northbound Interface and automatically distributed among the appropriate AMCs. Certain policies can be present during initialisation. To give an example of this rather abstract principle, the structure of the Management Clusters mentioned above is based on policies. They can, for example, control the number of nodes per cluster, but they can also contain criteria for the election of Cluster Head, such as memory resources, load etc.

## Connecting to the North

The Northbound Interface offers support for a higher layer Operation Support System (OSS) or another Network Management System to access Madeira’s network management functionality. From this point on, both the Operation Support System as the Network Management System will be referred to as OSS.

## Web Services

The communication between Madeira and an external OSS is based on Web Services. The information exchange between Madeira and the OSS will be encapsulated in SOAP messages. SOAP is an XML-based message format and although it can be used over a variety of protocols, the use of SOAP over HTTP is most common.

The Northbound Interface has one corresponding WSDL (Web Services Description Language) description. The WSDL specification is an XML description of the public interface to the Web Service. It contains information like protocol bindings, message formats and available operations and messages.

The network node that is running the Northbound Interface functionality can dynamically change as a result of network reconfiguration. Due to this, some functionality should be in place so the OSS can discover the new address. Madeira will

use an external UDDI (Universal Description, Discovery and Integration) registry to store the NBI address. It is an XML registry in which information on Web Services can be stored [10]. Fig. 7 shows the relationship between Northbound Interface, OSS and UDDI.

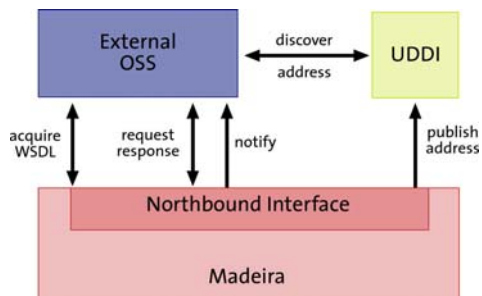


Fig. 7: Usage of Web Services for the Northbound Interface

As can be seen in Fig. 7 above, the Northbound Interface supports request/response as well as notifications as communication types between Madeira and the external OSS. For these notifications, the Northbound Interface acts as a notification producer [12]. The OSS will, naturally, act as a notification consumer. To be able to receive notifications, the OSS listens for SOAP requests. The most suitable solution would be that the OSS also implements a simple Web Service for this functionality.

## Capabilities

The Northbound Interface propagates instructions from the OSS to the platform, and to get data from the platform back to the OSS. In more detail, the Northbound Interface offers the following services, divided into five groups:

1. The OSS Connection Manager enables the OSS to (re)discover the Northbound Interface node. It publishes for example the address of the Northbound Interface in an external UDDI registry. It also responds to polling messages sent by the OSS to check connectivity with Madeira.
2. The Policy Manager can be used to add, change or remove policies to the Madeira Management System.
3. The Events/Notification Manager receives alarms and events from Madeira, and converts these messages to a format readable by the OSS. Notifications will be sent to every subscribed consumer. This means that

multiple Operation Support Systems can monitor the Madeira Management System.

4. The Network Manager provides information about the network topology and Management Clusters.
5. The Command Injection Manager receives commands from the external OSS, forwards them to the appropriate Madeira components for further processing and sends back the corresponding response to the OSS. The OSS can use the Command Injection Manager to disable Base Stations or to acquire a list of currently active alarms for example.

## The Madeira Scenario

The goal of the scenario is to prove the capabilities of the Madeira approach to deal with real life management problems. It provides a number of challenging tasks to test the management approach. To emphasize the strengths of Madeira, the problems that arise in the scenario are difficult to solve with traditional management approaches, especially with respect to dynamic reconfiguration and changing topologies that occur in WiFi networks.

The scenario focuses on the areas of Configuration Management and Fault Management, with an emphasis on the integration between both of them. In the scenario, a number of wireless base stations are deployed in such a way that wireless equipment (laptops or PDAs for example) may have coverage from one or more base stations. Not every base station has a wired connection to the back haul network, as is the case in a traditional wireless network. Base stations directly connected to the backhaul network are called gateways. The rest of the base stations can only use a wireless connection to reach a gateway and thus the backhaul network.

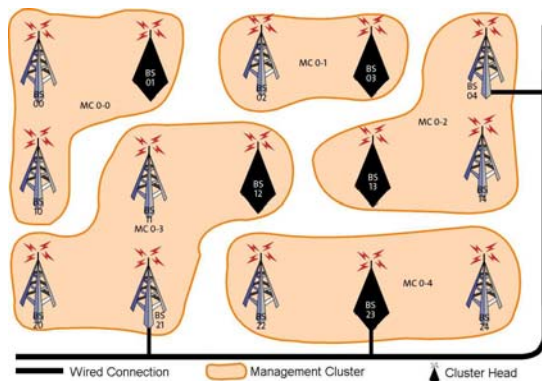
## Configuration Management

After deploying the base stations, Madeira automatically sets up the wireless meshed network using OLSR (Optimized Link State Routing protocol) as the routing algorithm. OLSR is a link stated routing protocol that is specifically developed for mobile ad-hoc networks [16].

Based on pre-installed policies, base stations are grouped into a number of clusters by the Grouping Service. These

policies can be based on a number of criteria such as number of nodes per cluster or topological proximity for example. Fig. 8 shows an example topology that could be the result of this process. As can be seen, clusters may or may not have direct backhaul connectivity. The network elements in a cluster monitor each other and exchange management information on a peer-to-peer basis.

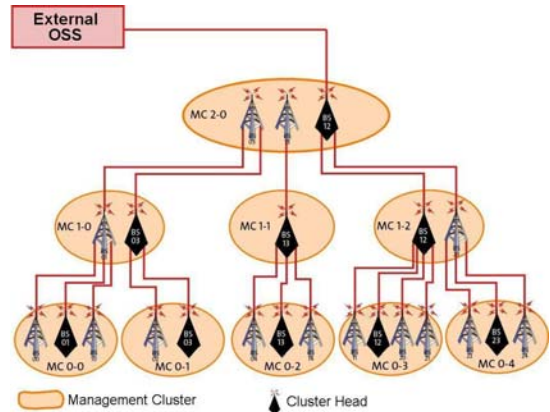
As mentioned, wireless network equipment that wants to use the network is in range of one or more base stations. If the wireless equipment is in range of more than one base station, it selects one of them as its preferred base station, and use this connection to use services on the Internet for example. If the wireless equipment is in range of just one base station, it must select that base station as its preferred base station.



**Fig. 8: Management Clusters formed in the Wireless Mesh Network**

Each cluster has exactly one Cluster Head. Policies are used for this election, and can be based on criteria like load, optimal connectivity or robustness. The Cluster Head is responsible for coordination and topology publishing of its cluster.

Different levels of clustering can exist in Madeira. Fig. 9 shows a possible clustering hierarchy that could be constructed in this scenario. The creation of this hierarchy is also based on policies. As mentioned in the previous section about the architecture, the top level Cluster Head is responsible for publishing the topology of the complete network. This can be done to a higher layer Operation Support System, or another Network Management System for example.



**Fig. 9: Management Cluster hierarchy**

The cluster hierarchy is the basic management overlay that is used by all management functionality in Madeira. It creates a scalable environment for network management. The Madeira Configuration Management application is responsible for the construction, maintenance and viewing of the topology. Other applications such as Fault Management use this management overlay to implement their functionality.

### Fault management

During usage of the network, it is inevitable that unexpected faults occur. When such a fault occurs, it is important that

- appropriate action is undertaken quickly in order to reduce the service impact, and
- meaningful information on the fault is presented to the operator (in particular in the cases where automatic restoration is not or not fully possible).

Besides Configuration Management (CM), Madeira focuses on Fault Management (FM) and how CM actions and events are related to faults detected by FM and reported as alarms. Correlation between CM and FM events is an important aspect in order to discover the actual cause of a problem in the network.

Alarms can be generated on different levels:

- Hardware level alarms are generated by the base station in case of a hardware fault.
- Platform and application level alarms are generated by either the Directory Service or the CM application. The Directory Service can indicate loss of connection with a neighbouring node, and the CM application can indicate changes in the topology (a node leaves or joins a

cluster).

When a fault occurs, the FM application will receive one or more alarms. For example, a hardware level problem may also cause a fault on platform level, creating two alarms. These alarms are correlated into a new alarm by FM and sent to the Cluster Head. This Cluster Head also performs correlation of the alarm with alarms originating from other nodes in order to get a clearer picture of the probable cause and possible solution. It can then forward the alarm to a higher hierarchy level. This process is repeated until it reaches the Top Level Cluster Head, which can notify the Northbound Interface in order to produce an alarm for the external OSS.

This paper provides a few example scenarios in order to explain the basic concepts and functionality of the FM application in Madeira. It describes two faults with similar impact but very different in nature (in the first case a node goes down while in the second there is just a loss of connectivity between two nodes), and focuses on the way Madeira distinguishes these two cases by correlating alarms and CM events at different levels of the management hierarchy.

### Base Station E outage

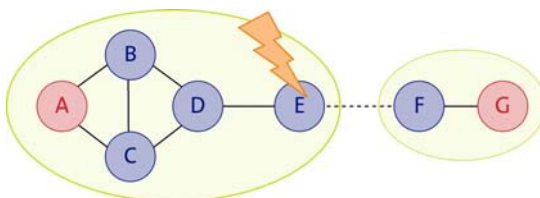


Fig. 10: Base Station outage

Fig. 10 shows two Madeira Management Clusters, with node A and node G being the Cluster Heads. The solid lines indicate 'physical' OLSR links between nodes. The dotted line represents an inter-cluster connection between node E and node F.

When node E fails, this will be noticed by the Directory Service of its one-hop neighbours D and F. Both nodes will notify their Cluster Heads that the link with node E has failed and that E might be faulty. Besides receiving this alarm from node D, Cluster Head A also receives a notification from the CM application that node E isn't part of the cluster anymore. It will then send an alarm with this knowledge to a higher hierarchy

level. When the Cluster Head G of node F receives the alarm that node E isn't reachable, it will also forward this alarm to a higher hierarchy level.

After receiving the alarms from node A and G, the higher level Cluster Head tries to correlate the information with other alarms. Since both alarms contain the same knowledge (a possible fault of node E) they will be merged to a single alarm with the same content. Afterwards the alarm will be forwarded up the hierarchy pyramid, until the Top Level Cluster Head will notify the NBI, which will inform the external OSS on the failure of node E.

### Link outage between D and E

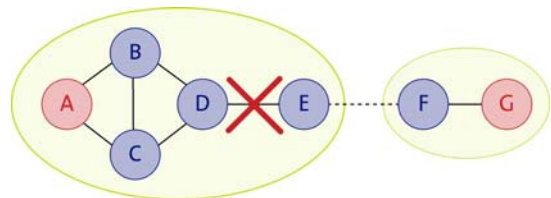


Fig. 11: Link outage

In this scenario, the link between node D and node E fails. The link between E and F remains intact. Both nodes D and E will receive a notification from their Directory Service indicating the neighbouring node is no longer reachable. Node D concludes E might be faulty and forwards this information to its Cluster Head A, who also receives a notification from the CM application that E is no longer part of its cluster. After combining this information, it will send an alarm to the next hierarchy level, identical to the previous scenario.

Besides receiving the notification from the Directory Service, node E will recognize that it is no longer connected to its cluster head and join another cluster (we assume that it joins the cluster containing F and G). After this reconfiguration process E will forward the information that D is no longer reachable to its new cluster head G which will additionally receive a notification from the CM application that E has joined its cluster and forward this information to the next hierarchy level.

The higher level Cluster Head of this next hierarchy level receives the alarm from A indicating that node D reported that E is unavailable and probably faulty. It also receives a notification from the CM application indicating that node E has joined

another cluster and an alarm from G indicating that node E reported that D is unavailable and probably faulty. After correlating these three notifications, the Cluster Head concludes that a link outage between D and E occurred and either suppresses this alarm (if configured to do so) or forwards this knowledge as a minor alarm up the hierarchy pyramid until the Top Level Cluster Head and NBI which will then inform the external OSS on the link outage between D and E.

## Future Work

Currently the project is focusing on the integration and system test of the Madeira prototype on a WLAN test bed of up to twenty nodes. Incremental design has been used during the development of the prototype, and preliminary test cases verifying the Madeira distributed network management system for a basic Use Case have been successfully passed. Future publications shall include a performance evaluation of the Madeira solution and an assessment of the application of peer-to-peer distribution techniques within the domain of network management.

The scope of the Madeira project will be further expanded over the next year (2007) to firstly build and integrate a seamless security solution, and secondly to evaluate and improve the scalability performance of the Madeira distributed network management system. Scalability shall be assessed using a custom-built emulator and extensive simulations, combined with results from the WLAN test bed.

## Conclusion

The Madeira Management framework proposes the use of peer-to-peer distribution techniques to fulfil management tasks. The ability to perform self-management and the usage of Management Clusters solves scalability issues that are present in current hierarchical network management approaches. So called Adaptive Management Components, or AMCs, that run on network elements, are in charge of performing the various management tasks. By using the peer-to-peer east-west interface, these AMCs can communicate with each other, creating a Management Overlay, which allows management tasks to be distributed and executed on the network nodes themselves. This in turn enables self-management of the

network nodes at Cluster level, thus improving scalability, response time, fault correction, and overall system performance.

Furthermore, because of the peer-to-peer concept, Madeira doesn't need a central server. Besides reducing operating and capital expenses, this also eliminates the single point of failure (and high redundancy requirements) that exist in traditional systems.

Madeira also offers support for a higher layer Operation Support System (OSS). Such an OSS can access Madeira via the Northbound Interface. This Web Services based interface enables an OSS to acquire full network inventory and topology information on a dynamic basis from the Madeira Configuration Management Application, receive "single root cause" correlated alarms from the Madeira Fault Management Application, introduce policies to configure and adapt the management logic, and perform other standard management tasks. By using a publish/subscribe system for notifications from the network, Madeira can notify multiple external systems about events or alarms at the same time.

The Madeira Fault Management Application correlates alarms at Cluster level and performs self-corrective actions, significantly reducing the number of alarms sent to the Operator, and also reducing the Operator intervention required. The Madeira Code Distribution Service facilitates the automatic deployment and restoration of services in the network, again minimising Operator intervention and hence reducing operating expenditure.

In order to prove the feasibility of the Madeira approach and to assess the performance of the Madeira distributed network management system, a challenging scenario has been identified, dealing with Configuration and Fault Management of large-scale dynamical WLAN networks: their deployment, and network formation and reformation due to mobility, faults, deployment of new services etc. A prototype is currently being developed and tested on a WLAN test bed of up to twenty nodes.

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## GLOSSARY

3GPP	3rd Generation Partnership Project, <a href="http://www.3gpp.org/">http://www.3gpp.org/</a>
AMC	Adaptive Management Component. Peer-to-peer aware components that interact with each other in order to perform management tasks.
CM	Configuration Management
CORBA	Common Object Request Broker Architecture. Language independent distributed object oriented framework.
eTOM	enhanced Telecom Operations Map
FM	Fault Management
J2EE	Java 2 Platform, Enterprise Edition
NBI	Northbound Interface. Enables an external OSS to acquire management data and configure the Madeira management system.
NE	Network element.
NGOSS	New Generation Operations Systems and Software
OLSR	Optimized Link State Routing protocol
OSS	Operation Support System. System to support the basic operation for service providers.
OSS/J	Operation Support System through Java
P2P	Peer-to-peer. Communication structure where nodes can communicate directly to each other without interference of a central entity.
SOAP	W3C protocol for exchanging XML-based messages
TMF	TeleManagement Forum
TMN	Telecommunications Management Network. Framework for the management of communications networks, developed by the ITU-T (International Telecommunication Union Telecommunications sector).
TOM	Telecom Operation Map
UDDI	Universal Description, Discovery and Integration. Platform-independent XML registry for Web Services
WSDL	Web Services Description Language
XML	eXtensible Markup Language

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