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Abstract— **The present paper describes functions and procedures of FUTON Radio Over Fiber Manager to operate with upper (network) and lower (physical) layers used in the transport of the wireless signals between a Central Unit (CU) and Remote Antenna Units. Also, it presents some mechanisms and procedures to be used in case of failures, while enabling end-to-end service problem resolution and service quality management by the FUTON Middleware. An overview of current RoF Management solutions is initially presented. The paper then addresses some of the challenges identified in [1], namely the specification of Radio-over-Fibre (RoF) manager entity functions that controls FUTON optical infrastructure; definition of the interoperability with the FUTON Middleware and Radio Resource Management; and definition of RoF Management functions which are tightly correlated and integrated with the radio and optical interface, physical layer algorithms in place, and FUTON radio resource management algorithms.**

Index Terms—Radio over Optical Fiber, Fault Management, Crosslayer design, Middleware

I. INTRODUCTION

The new FUTON optical-radio architecture brings new challenges regarding the network management, fostered from the use of multiple technologies derived from heterogeneous wireless access networks. Hence, FUTON aims at technology agnostic, multi-layer services management, in order for the management of deployed services to become independent of the underlying technology. Improved scalability will imply the possibility to manage more resources over more technology-diverse networks.

The objectives of FUTON Network Management System (NMS) are hence aligned with the NMS specifications for Next-Generation Networks (NGN). The RoF Manager architectural concept includes cooperative RoF Manager instances per CU to manage a multitude of network domains over different technologies. The management solution must therefore cope with the provisioning, connection outage, and performance management of the RoF infrastructure through re-usable components that may be applied in all network management sub-systems and security of the Network elements in the network.

II. FUTON ARCHITECTURE

The FUTON project [1] aims to develop a hybrid fibre-radio network that interconnects multiple Remote Antenna Units (RAUs), transparently carrying radio signals to/from a CU, where joint processing takes place. The generic architecture of FUTON is intended to cover a geographical area that is divided into several serving areas, where the multifrequency RAUs are located. These RAUs are linked to a CU, using a transparent optical fibre system, and can send/receive signals from different wireless systems.

The processing tasks concerning all communications within a serving area are performed at the correspondent CU. For distributed wireless systems, the availability of the radio signals at a common location allows the joint processing of the signals from different RAUs, enabling the development of virtual Multiple-Input Multiple-Output (MIMO) concepts for broadband wireless transmission and also inter-cell interference cancellation. In addition, heterogeneous wireless systems can be co-localized, which allows the use of a common management platform. In this context, cross-layer algorithms may be developed to optimize the usage of the radio resources, and may be generalized to cross-system model, enabling the development of efficient Common Radio Resource Management (CRRM) algorithms. Figure 1 depicts the FUTON scenario where several systems coexist in the same serving area, representing also the main modules of the CU to which all of those systems are connected.
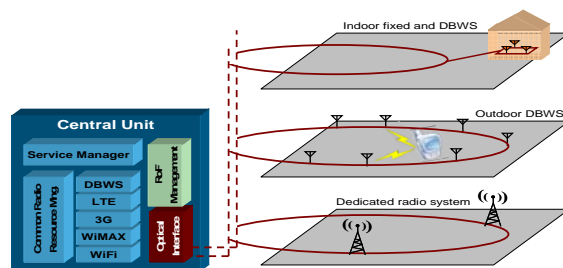
Figure 1 FUTON generic architecture.

From a practical point of view, FUTON consists of a fixed infrastructure that provides enough flexibility to share its resources by a wide range of wireless systems and by fixed optical connections, instead of being dedicated to a single system. The supported systems should include, among others, outdoor Distributed Broadband Wireless Systems (DBWS), where the infrastructure acts as a virtual MIMO enabler to achieve the target high bit rates, indoor distributed broadband systems, and also the remote control of dedicated radio

systems. DBWS is the technology envisioned within the scope of FUTON to cope with the IMT-A requirements. Its operational model includes functionalities of the three bottom layers of the OSI model.

The technical work within FUTON will concentrate in the following innovative elements: Distributed Broadband Wireless Systems for the central processing of signals from DAS; New optical components and technologies for transporting RoF signals from the RAUs to the CU; Optimization on the usage of heterogeneous radio resources; and Network management of heterogeneous network, which is addressed by this paper.

A. FUTON RoF Manager

The RoF Network Manager is expected to manage the network equipment and the communication links, while enabling end-to-end service problem resolution and service quality management by the FUTON Middleware.

This component is responsible for managing data transfers between RAUs and the CU, providing the functional and procedural means to transfer data in the Radio Over Fiber infrastructure. RoF Manager scope is shown in Figure 2, considering RAUs supporting different radio access technologies. In case of many antennas serving the same mobile terminal (e.g. MIMO), the Middleware queries the RoF Manager for the channels en route of all the antennas serving the terminal. Optionally it could also provide alternative paths in case of failure.
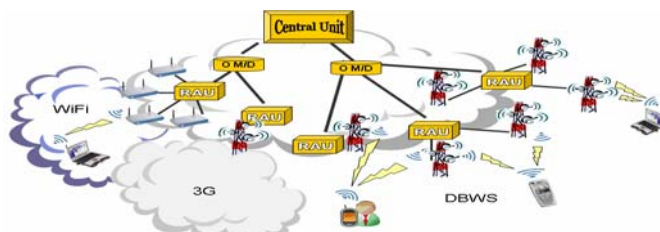

Figure 2 – RoF Manager scope

III. OVERVIEW OF RoF MANAGEMENT SYSTEMS

The network management solution plays a very important role in the RoF environment which consists of heterogeneous network characteristics, different applications, various user classes and wide variety of services. Preceding Network management systems are based on two approaches viz. Telecommunications Management Network introduced by ITU-T and Simple Network Management Solution adopted by the IETF [2]. These solutions cater to requirements arising from different network systems individually. But RoF manager must be capable enough of serving network traffic emerging from all kinds of technologies such as such as PSTN, PSDN, PLMN, WLAN, WiMax, ultrawide-band (UWB) signals, and DBWS signals. There are some possible answers.

Policy based network management (PBNM) system is one hypothesis [3]. PBNM employs a policy based approach in administering network resources, quality of service, security. These policies are "set of rules that determine the network management distributed system behavior". The information

model and policies are kept independent of the network management protocols. This brings in automation and simplifies the process of network management. Adding or changing the policies is sufficient to tackle changing situations. In the PBNM system, a policy server is employed to make the decisions, also known as the Policy Decision point. Policy Enforcement Point interacts with the policy clients. The policies are stored in a data repository [2]. The difficulty faced in a PBNM system is the conflict between policies. Algorithms are thus needed to check the policy conflicts.

While some authors proposed management protocols to be used to manage network elements in IMS ([4] proposed a network management solution, which can be used to manage IMS components independent of heterogeneous management protocols like WBEM, SNMP, JMX), the management of elements on the network core is out of RoF Manager scope.

A. RoF Management Solutions - Overview

There appears to be currently a lack of technologies concerning specifically RoF management. The comprehensive study described in [5] is purely focused on investigating RoF transmission alternatives. Previous work with some relevance to RoF Management includes [6], which proposes a hybrid ROF wireless sensor network (RWSN) architecture, in which the RAU (on the scope of a RoF solution) is viewed as a heterogeneous cluster head sensor node. The authors describe a simple topology control algorithm and data collection protocol, and further analyse network delay and energy consumption.

B. Fault and Performance Management Overview

One of the main components of a network management system, responsible for running a network at optimum level and concerned with the detection, isolation and recovery from faults are the fault and performance management systems. Much attention has been paid to fault correlation which is the base work for most of the network management tasks. The main fault processing logic is located in the correlation engine at the top of the alarm processing chain [7]. Proper algorithms dependent on a set of attributes using root cause analysis can find out the alarm origin. But there are drawbacks residing in this system such as scalability issues, issues related to intelligent fault management, fault localization scheme, etc. FUTON will exhibit a scenario where exists a large number of emitting nodes and alarms which will surely cause a bottleneck problem in the correlation engine. The heterogeneous nature of the network will increase the problem from the complexity point of view. Moreover, these fault management systems are built taking into consideration that the network will be static. But the RoF system is expected to be dynamic and this is certain to bring inconsistency in the system behavior [7].

RoF Manager requires fault management system to detect, log, and notify users of problems and, if possible, to mediate between the Middleware and the NEs to automatically fix network problems, keeping the network running effectively, since faults can cause downtime or unacceptable network

degradation. Therefore, the fault management system should bring down operational expenditure. While designing fault management system for RoF Manager, it should be taken into account that, there will be large number of nodes, heterogeneity will exist from hardware, software, vendors, various access and communication protocols and system will be dynamic in behavior. A good solution for this large population is scalable fault management solutions [8]. Solutions based on autonomic computing will cater to self-management. [9] proposes a framework to add autonomic computing to network fault management system by including a monitor and control loop.

The main functionalities of Fault Management module in RoF Manager are fault filtering and correlation, fault localization, fault analysis and fault reporting. Fault correlation is used to determine and find out related alarms for each of the new alarm that is generated. Once identified, all related alarms will be merged into a new one. Fault localization identifies the source of failure. while timely resolution defines the characteristics to discover the failure in predefined time. Fault analysis component will decide, which alarms are forwarded to the next level, based on the alarm severity. And finally the fault reporting will forward the alarm through Northbound interface.

The authors in [10] have made some study on the performance requirements of a similar network system like RoF. They have proposed a visualization model looking towards the real time performance management of next generation networks. Performance management was kept as one of the most important concepts in the proposed Diadalos platform [11]. This work [11] presented an integrated architecture based on IEEE 802.21, aiming to maximize benefits by efficient performance management of underlying networks.

Performance management subsystem in RoF manager provides the means to evaluate and trace the performance of the network. Key Performance Indicators about NEs, links, system behavior are measured, which are used for decision mechanisms. Performance management consists of two components. One of them comprising of a set of functions that evaluates and reports on the equipment behavior and NE effectiveness. Another component includes gathering of statistical information, maintaining and examining history logs, determining system performance and alerting system modes of operation. A policy based performance management is considered in this regard.

C. Configuration Management Overview

A multi-objective optimization technique for cost effective deployment of radio over fiber technology was proposed by [12], aiming at providing connectivity using Voronoi Diagrams.
In [13], it is described a RoF-system experiment at 60 GHz with a photonic dynamic channel allocation (DCA) capability for four channels on WDM. According to the authors, optical physical layers have a wavelength-routing capability to provide DCA to the wireless services operating on top of the network stack. [14] proposes a scalable network management system which is useful in scenarios with large user population,

heterogeneous networking technologies, complex geographical terrain and unpredictable nature of the network. This is similar to RoF environment. This uses a manager-agency paradigm along with adaptive configuration management system implemented using CORBA.

Configuration Management (CM) consists of acting on network and system configuration information so that the effects of specific hardware and software can be managed and tracked. Change management is a part of configuration management. Change management is concerned with keeping track of hardware configurations and changes, while maintaining their status update. Ex: Addition of new hardware, New optical paths etc.

D. Security Management Overview

The Heterogeneity in the technologies, and the applications obtained using hybrid optic-radio infrastructure, and sharing of common infrastructure by many Network Elements like RAUs, Optical components and other subsystems, gives raise to security issues. The goal of security management in RoF Manager is to provide security to the Network elements. The services provided by this module are Authentication, Authorization, Integrity and Confidentialty of messages.

AAA based protocol is one solution to provide these services. All the NEs like RAU, CU, Switches/Routers etc are to be authenticated by the RoF manager before giving any service to them. RoF manager includes AAA client, which takes the requests from the NEs and forwards the requests to the AAA server. The client will forward the request to AAA server in a header format with the proper attributes included in the message. Also the NEs need to be authorized by the RoF manager to access other resources or a particular service. The integrity and confidentiality of messages between NEs is taken care by the security management protocol.

IV. ROF MANAGER & MIDDLEWARE INTEROPERATION

The FUTON system is composed by a hybrid optical-radio infrastructure allowing for transferring data between network nodes, here called Central Units (CU), and the wireless access units using Radio Over Fiber (RoF) technology. The data exchange between the CU and the Remote Access Units (RAU) is done through the Joint Processing Unit (JPU) and managed by a component called RoF Manager present inside the CU. In this paper we will describe the functions and procedures of RoF Manager carried out in the operations with network and physical layers.

Each RAU can handle more than one antenna, and the data transferred to and from each antenna is forward in an exclusive RF carrier (here also referred as channel) known by the Antenna's RAU and the CU. This is different from UMTS where the routing is digitally processed at the Radio Network Controller (RNC) (see Figure 3). To be aware of the link to each antenna, the RoF Manager must know that a specific RF channel, in a specific wavelength attached to a specific port (fiber) is related to a specific antenna of a specific RAU. RoF Manager provides addressing and control of the wavelengths and RF carriers that connects each antenna. Each antenna caters to a specific technology and in this way different

technologies can be handled.

A. Channel physical address

For the interaction between physical layers and upper layers, the RoF Manager specify a physical address to each channel, computed from the port, the wavelength and the RF carrier used by the link. For each central unit, the physical address is a distinctive optical channel identification, given by PHY_ID, computed as:

$$PHY\_ID = c + w * MAX\_C +$$
$$+ p * (MAX\_C * MAX\_W) +$$
$$+ j * (MAX\_C * MAX\_W * MAX\_P) \tag{1}$$

where j is the index of the card, p the index of the port of the given j, w the indexes of the wavelength of the given p, and c is the index of the carrier of the given w. Also, MAX_P, MAX_W and MAX_C are respectively the maximum available index for p, w and c, regardless of their state. Defining MAX_C, MAX_W and MAX_P as powers base 2, the operations required in (1) can be easily computed by employing binary shift operators. Let nC, nW and nP be respectively the logarithms base 2 of *MAX_C*, *MAX_W* and *MAX_P*. Using the left shift operator (<<), the value of PHY_ID came given by:

$$PHY\_ID = c + (w + (p + j << nP) << nW) << nC \tag{2}$$
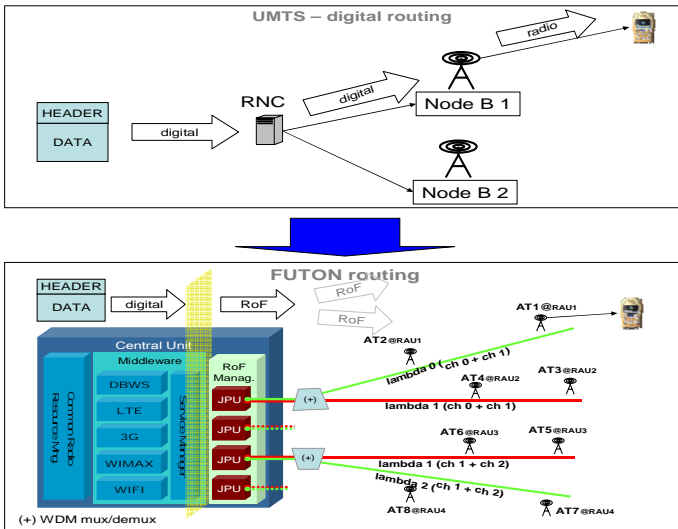
Figure 3 – Routing: UMTS vs FUTON approach

B. Channel forwarding table

The RoF provisioning subsystem provides to the MAC layer a channel forwarding table (CFT) that reflects the channel distribution among the different RAU/Antennas. It consists of a table with the physical address of the antennas (ANTENNA_ID), here identified by RAU$_i$/ANT$_j$, matched with the channel ID attached to the antenna (PHY_ID). The table 1 below shows an example of a CFT, assuming MAX_C = 8 and MAX_W = 4. The index of the ports (p), wavelengths (w) and channels (c), required to compute PHY_ID, are shown for clarification only.

Table 1 – Creation of the channel forwarding table (CFT)

ANTENNA_ID	Parameters			PHY_ID
	p	*w*	*c*	
RAU 1 / ANT 1	*0*	*0*	*0*	0
RAU 1 / ANT 2	*0*	*0*	*1*	1
RAU 2 / ANT 1	*0*	*1*	*0*	8
RAU 2 / ANT 2	*0*	*1*	*1*	9
RAU 3 / ANT 1	*1*	*0*	*0*	32

The following section outlines the procedures between RoF layer and upper and lower layers.

C. RoF to network layer

The network layer combines the data to the mobile terminals covered by a specific antenna and forwards it to the channel linked to it, after querying CFT for its PHY_ID. Using a CFT table, the upper layer only has to know the MAC address of the antenna serving each mobile terminal. Using this procedure, when the channel configuration changes (statically or dynamically), is only required to update the CFT.

In addition, the CFT table provides a field with the channel status, as illustrated in table 2, allowing for the network layer to be ware of the antenna's link status. Remember that a link to an antenna is a RF channel in a wavelength known by both CU and RAU.

Table 2 – Complete Channel Forwarding Table (CFT)

ANTENNA_ID	PHY_ID		STATUS
	decimal	binary	
RAU 1 / ANT 1	0	000000	1 (enable)
RAU 1 / ANT 2	1	000001	0 (disable)
RAU 2 / ANT 1	8	001000	2 (failure)
RAU 2 / ANT 2	9	001001	2 (failure)
RAU 3 / ANT 1	32	100000	1 (enable)

D. RoF to physical layer

Given the PHY_ID is also possible to retrieve the index of each element (j, p, w or c), knowing the values of MAX_C, MAX_W and MAX_P. This makes possible for the physical hardware (e.g. Joint Processing Units) to identify the port, the wavelength or the RF channel of the link identified by PHY_ID. This is shown in equations (3) to (6).

$$c = MOD(PHY\_ID; MAX\_C) \tag{3}$$

$$w = MOD\left(\left\lfloor \frac{PHY\_ID}{MAX\_C} \right\rfloor; MAX\_W\right) \tag{4}$$

$$p = MOD\left(\left\lfloor \frac{PHY\_ID}{MAX\_C * MAX\_W} \right\rfloor; MAX\_P\right) \tag{5}$$

$$j = \left\lfloor \frac{PHY\_ID}{MAX\_C * MAX\_W * MAX\_P} \right\rfloor \tag{6}$$

The equations (3) to (6) provides a general description of how to determine the index of each channel parameters. However, assuming nC, nW and nP as defining in (2), the channel parameters can be also achieved by:

$$c = MOD(PHY\_ID, 2^{nC}) \tag{7}$$

$$w = MOD(PHY\_ID >> nC, 2^{nW}) \tag{8}$$

$$p = MOD(PHY\_ID >> (nC + nW), 2^{nP}) \tag{9}$$

$$j = PHY >> (nC + nW + nP) \tag{10}$$

The time required to perform the channel identification is critical, as it has to be done in real time. However, the MOD function is a computationally light operation, knowing that $MOD(x, 2^n)$ is equal to the n rightmost bits of x.

E. CFT update after failure

The update of the status in the CFT must be carried out in all the channels affected by the malfunction device. If a failure

occurs in a port, the status must be updated in all the RF channels of any of the wavelengths tied to that port. If the malfunction occurs in a specific wavelength of a port (e.g. due to a laser failure), the status is updated in all the RF channels of that wavelength.

This is done in order to allow for the upper layer to easily know the status of the links (or channels) to any antenna. However, the failure notification to the Fault Manager only alerts for the failure device, to avoid a cascade of notifications.

The procedure to identify and modify the status of the channels affected by the failure is based on the device ID where malfunction was detected. Each device ID is given by:

$$JPU\_ID = j \quad (11)$$
$$PORT\_ID = p + j << nP \quad (12)$$
$$WAVE\_ID = w + p << nW + j << (nP + nW) \quad (13)$$

assuming MAX_C, MAX_W and MAX_P as powers base 2 and the definitions used in (2).

When a device with a given ID fails, the statuses of all the channels which prefix match the ID of the failing device are updated. The identification of the devices used by each PHY_ID channel are given by:

$$WAVE\_ID = PHY\_ID >> nC \quad (14)$$
$$PORT\_ID = PHY\_ID >> (nC + nW) \quad (15)$$
$$JPU\_ID = PHY\_ID >> (nC + nW + nP) \quad (16)$$

For better elucidation, in table 2 we can see an example of a failure declared in all the channels that use the wavelength with ID = 1 of the port with ID = 0 (WAVE_ID=1). As MAX_C = 8 (nC = 3), it follows from (14) that channels 0 and 1 use the wavelength 0, channels 8 and 9 use the wavelength 1 and channel 32 use the wavelength $100_{(bin)}$. Though, the only channels affected by this failure are channels 8 and 9.

For simplicity, in table 1 and table 2 is presented an example where each RAU processes only one wavelength, and each channel of the wavelength is associated with each antenna of the RAU. Nevertheless, the same wavelength can be shared by different RAUs, regarding that each channel is connected to only one of the RAUs.

F. Fault Localization

The usage of the CFT may play an important role in the intelligent fault management and fault location. Due to the way the PHY_ID is defined, is possible to infer the malfunction device by correlating the PHY_IDs of the failing channels. For example, correlating the PHY_IDs of the channels 8 and 9 in the table 2 we can see that the failure occurs in the channels which PHY_ID starts by 00100. As there is no fully working channel starting by 00100, one can presume that the failure occurs in the device with the longer ID fully contained in 00100 (starting from the left). The answer is a presumable failure in the wavelength identified be ID = 001, as occurred.

V. CONCLUSIONS

Telecommunications networks systems are complex environments to be managed, since they change and develop continuously and are subject to several causes of faults for which a rapid decision is imperative. FUTON access networks

heterogeneity, and the radio signals transport from such networks over optical fibers, adds more challenges into such an environment.

This paper presented an overview of state-of-the-art research work relevant for RoF management, which the authors conclude is still a scientific field lacking significant previous research work applied to RoF scenarios. This paper proposes a simple and fast mechanism to model the interactions between physical layers and upper layers, which supports not only static but also dynamic re-configuration scenarios.

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