ETARE : ENABLING TECHNOLOGIES FOR SDR COMPLIANT TACTICAL NETWORKS MOBILE AD HOC WIDEBAND WAVEFORM(S)

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ABSTRACT

The need of a flexible radio interface Architecture has been identified as a mean of facilitating migration to the next coming Mobile Ad Hoc Wideband Waveform and the integration of new waveform technologies. Future Ad Hoc networks will link together different elements on the battlefield (vehicles, foot soldiers, helicopters, etc.) and possibly connect them with naval forces. New generation waveforms will have to provide improved networkability between the forces and will support a wide variety of services.

The EDA ETARE project main objective is to develop advanced waveform technologies that could be included in these future national or coalitional radio interfaces and to elaborate a generic radio interface architecture, an adaptive protocol stack with cross layer designs. This paper focuses on the generic architecture that is compliant with SCA implementation, and presents some examples of behavior adaptation to typical operational scenarios.

1. INTRODUCTION

Ad Hoc tactical networks are evolving towards a variety of applications with different Quality of Services, from low to high data rate, with latency constraints from real time to relaxed latency. Services can be either packet oriented or connection oriented.

One major challenge is to guarantee interoperability between fleets of mobile equipments from various manufacturers, in networks deployed at national and/or coalitional level. For that purpose, future radio technologies should provide standardized interfaces.

Another challenge is to reduce the cost of development, production and maintenance while improving product confidence.

Ad Hoc tactical networks that will shortly appear on the European level will be operated in a context of scarce frequency spectrum availability so that next generation radio interface will have to support bandwidth usage flexibility.

Those topics have been addressed in the ETARE project. ETARE (Enabling Technology for Advanced Radio in Europe) is an EDA Ad Hoc type B R&T project funded by Italy (leader), France, Belgium, Finland, which aims to develop waveform technologies for introduction to future Wideband Waveform (WBWF) definition at national or coalition level. One of the goals of the project is to design a generic WBWF architecture. It addresses the challenges of inter-operability and scarce radio frequency spectrum usage, and draws up a framework for the standardization of interfaces and protocols. The target equipment is Software Defined Radio (SDR) compliant platforms for operation in tactical networks.

This article focuses on the ETARE generic protocol architecture and presents some examples of behavior adaptation to several operational scenarios.

Section 2 introduces the targeted operational scenarios and the ensuing WBWF requirements. Section 3 presents the WBWF architecture : its perimeter, the QoS structure, the protocol stack and the features of each layer.

Section 4 illustrates how the ETARE WBWF architecture handles flat networks as well as clustered organization of the coverage area, and how it is possible to a terminal equipment to switch from one routing structure to another one.

ETARE WBWF architecture is compatible with several multiple access schemes (TDMA, OFDMA, CDMA, hybrid schemes), as shown in section 5. Section 6 presents an example of cooperative MIMO handling.

2. OPERATIONAL SCENARIOS AND WBWF REQUIREMENTS

2.1. Operational scenarios

ETARE addresses several operational scenarios :

- On The Move (OTM) : the network is a multi-hop mobile ad-hoc network. It handles self organization of mobile terminal equipment communications including high data rate services. Mobile terminals can be of several types e.g. portable, vehicular, aero-mobile.

- At The Halt (ATH) : the network contains fixed or semi-fixed terminals that act as a backbone in order to interface with HW, logistic centre infrastructure, or other OTM network. This can be accomplished e.g. with a mobile terminal equipped with a gain mast antenna : the terminal waveform is then reconfigured to support enhanced communication capability associated with ATH services requirements (higher data rate, long range coverage).
- Naval and Land Interworking (NLI) : WBWF is designed to handle communication between maritime terminals (boat mounted equipment) and land OTM terminals.

Other operational scenarios are considered such as Weapon System Waveform including sensor networks and special operating modes like silent mode and LPI/LPD modes. The present paper focuses on OTM, ATH and NLI scenarios.

These scenarios are associated to different system characteristics (non exhaustive list) :

- Types of missions and coalition configuration, which means different security levels,
- Types of terminals with different capabilities and behavior (power management, support of classes for traffic and related Quality of Service (QoS), etc.) : vehicular, portable, aero-mobile, sensor,
- Types of operational theatre, thus different propagation environments, interference conditions and needs of signal discretion. Coverage areas can be densely as well as sparse deployed areas.
- Types of traffic with varying QoS requirements (IP services, connection oriented services, connectionless short messages, etc.),
- Types of network topology and densities,
- Frequency bands : although the NATO UHF band is considered in a first step as the core band for OTM scenarios, other frequency bands can easily be accommodated either in a static manner (at mission configuration) or in a dynamic way during operation depending on variations of frequency availability. The later point allows cognitive radio to be handled. In the same way, potential rescheduling of NATO UHF band can be easily supported,
- WBWF may have to face scarce radio resource availability, especially in a dense area (above 200 nodes) so that spectrum efficiency and signaling consumption must be optimized.

2.2. WBWF architecture requirements

The various ETARE scenarios require that the architecture should handle QoS and security adaptation and thus it should support :

- Several multiple access schemes TDMA OFDMA SC-OFDMA, Frequency Hopping and/or Direct Sequence CDMA (DS-CDMA FH-CDMA), and any combination i.e. hybrid access schemes and transitions between them.
- dynamic physical layer configuration for transport format adaptation,
- QoS adaptation with radio resource management algorithms for link adaptation
- Optimization of spectrum efficiency and signaling consumption, through mechanisms such as clustering adapted to topology behavior : Relaying radio flows through intermediate node in either a flat or clustered approach. This means supporting several routing strategies and protocols. Thus three degrees of topology are considered :
  - Flat routing,
  - Clustering of the management of radio resources i.e. one node, called the Cluster Head, allocates resources to its neighbors while the traffic remains distributed i.e. transit directly between nodes without passing through the Cluster Head. Cluster Gateways are nodes at interconnection between two clusters.
  - Hierarchical clustering i.e. nodes are organized in a hierarchical tree topology and some of the nodes centralize traffic for their upper level.
- Security with the protection of :
  - the intra-network protocol signaling (NETSEC),
  - traffic and signaling information that transit over the radio interface (COMSEC),
  - the physical signal (TRANSEC).

Another important point is that the generic ETARE WBWF architecture should motivate the future standardization of the interfaces for inter-operability. For that reason it takes into account relevant standards and developments that were accomplished in the civil telecommunication industry and inherits a similar OSI and cross layer behavior.

ETARE architecture is flexible enough to accommodate progressive insertion of future technologies.

3. ETARE WBWF ARCHITECTURE

3.1. WBWF perimeter

ETARE WBWF is in charge of protocols that are related to the physical medium i.e. to the radio interface so it handles all the features from the physical layer to radio ad-hoc networking. It is designed to be able to interconnect to other networks to establish an IP compatible tactical network through the notion of standardized (open) interfaces.

Using an analogy with the language used in civil 3G standards, the ETARE WBWF domain is the Access Stratum. Its perimeter is illustrated in Figure 1. The interfaces with Non Access Stratum (NAS) are to be standardized through Classes of Services (CoS).

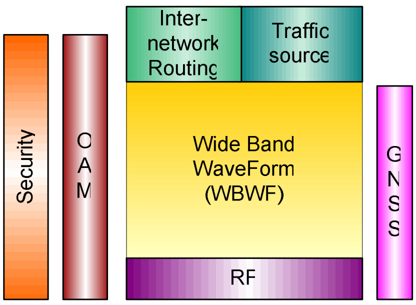

Figure 1 – ETARE WBWF perimeter

At the top level, ETARE WBWF interfaces with traffic source (either IP or non IP traffic) and inter-network routing. ETARE WBWF takes charge of the multi-hop radio paths routing within a radio coverage area, and of the QoS. At the bottom level, ETARE WBWF interfaces with the RF module through the DAC/ADC converter i.e. at the modulated symbol level.

ETARE WBWF provides facilities for ciphering in addition to the one applied at the application level. This allows protection of intra-network protocol signaling. NETSEC, COMSEC and TRANSEC are supported.

Interface with Operation Administration Maintenance (OAM) allows local and/or remote supervision (here remote means over the radio interface). As an option ETARE WBWF can be interfaced with a GNSS receiver for positioning and synchronization features.

3.2. QoS Architecture

The End-to-End CoS is managed at the Non Access Stratum level with the support of the Access Stratum i.e. of the WBWF. As an example, for IP services, collaboration between Access and Non Access Stratum is done with the Differentiated Services Code Point (DSCP) field of the requested CoS.

Within the Access Stratum, two levels of QoS are defined : at the radio link level between two neighboring nodes and at the routing level between border nodes.

CoS is converted into WBWF QoS during the negotiation phase at service establishment. WBWF QoS is characterized by : minimum and/or maximum rate, maximum transfer delay, delay jitter, error ratio, radio bearer priority, maximum number of radio hops, etc. Those QoS parameters are converted into routing parameters (for the routing algorithm) and transmission parameters (i.e. modulation, channel coding, …).

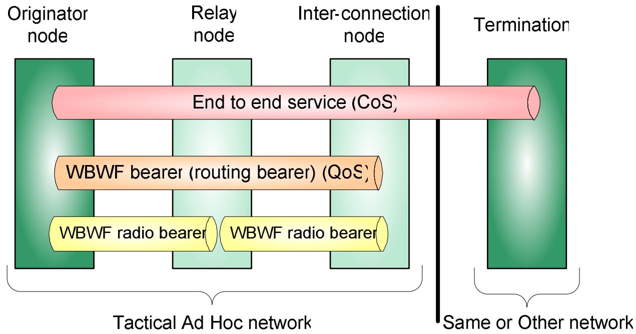

Figure 1 – ETARE WBWF QoS Architecture

The ETARE has shown that QoS in radio networks must take interference into account. Mechanisms to handle QoS in radio networks have been identified in ref. [1] and [2] and dedicated mechanisms to handle QoS in TDMA-based radio networks have been proposed in ref. [3].

3.3. Protocol stack

The WBWF protocol stack inherits an OSI layered structure and is enriched with a cross-layering approach. It also supports the structure of levels of information from 3G civil standards i.e. logical, transport and physical channels and the concepts of transport format.

WBWF is made up of four planes : the User, the Control, the Management and the Security planes. The User plane follows OSI rules while the Control, Security and Management planes carry out cross layering.

The User plane takes charge of data and signaling exchanges over the radio interface. Communication between layers is handled with service primitives through Data Service Access Points (SAP).

The Control plane configures the User plane and handles radio resource allocation and routing algorithms. Cross layer exchanges of information are handled through Control SAPs.

The Security plane takes charge of every security feature and is configured according to the security level of a given mission. It secures protocol layers through Security SAPs.

The Management plane guarantees proper configuration and supervision of layers, and is compatible with SCA requirements. It accesses to the protocol layers through Management SAPs.

The protocol stack is illustrated in Figure 3.

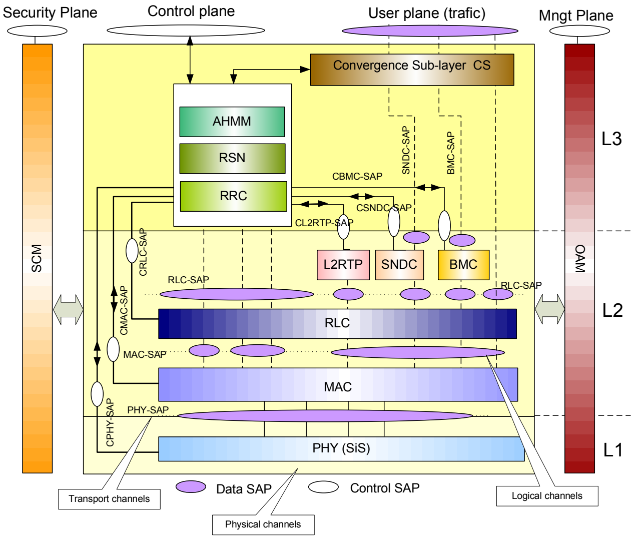

Figure 3 – ETARE WBWF architecture

The Convergence Sublayer (CS) carries out the interface with different types of services and manages the sessions (IP, connection-oriented, connectionless short messages, etc.). It makes use of Ad Hoc Mobility Management (AHMM) services to access a coverage area.

AHMM is a complement to NAS Mobility Management and to routing. It handles mobility features between Location Areas. AHMM facilitates interoperability between several coalition or operational groups at waveform level i.e. sharing of the radio interface between several operation groups. In case of clustering, it handles mobility between clusters or groups of clusters that are belonging to different areas (attachment, registration, paging, etc.). In the case of hierarchical clustering, AHMM manages location areas (groups of coverage areas). AHMM is under the control of the Security Plane for peer entities authentication and nodes' banishment/de-banishment. AHMM makes use of Radio Sub Network (RSN) for access to routes.

RSN provides Ad Hoc Radio Networking as a complement to NAS routing, i.e. all the routing processes such as presence detection, neighbor construction, route selection, etc. It can support both reactive and proactive protocols. In the case of a clustered approach, RSN takes charge of cluster management (creation, modification, deletion). RSN makes use of Radio Resource Control (RRC) to adapt routing decisions to radio conditions and to effectively activate a radio link associated to a virtual route.

RRC controls the configuration for access to radio resources locally to a node in case of flat network. It is the one that decides the carrier frequency and the set of transmission modes (coding scheme, ARQ protection, MIMO configuration, etc.) that can satisfy the requested QoS. In case of clustering, the RRC instance located in a Cluster Head controls the radio resources of the nodes located in its clustered area and informs them of the parameters that it has allocated to them. It is able to collaborate with adjacent Clusters Heads. RRC monitors radio link state : it collects and filters lower layers measurements as well as peer entities for the instance located in the Cluster Head, and reconfigures the radio resource accordingly. RRC also manages load balancing between radio links, long term (slow) power control and fast power control parameters. RRC implements algorithms that depend on the multiple access scheme. In the case of DS-CDMA, it handles macro-diversity (linked to cooperating routing). With TDMA and/or OFDMA, RRC handles sub network synchronization and handling of timing advance protocol.

AHMM, RRC and RSN belong to the control plane. Their signaling PDUs are passed to Radio Link Control in the User Plane for transmission to their peer entity.

SubNetwork Data Convergence (SNDC) adapts IP traffic flow to the WBWF radio interface. It supports both IPv4 and IPv6. Header compression can be activated and several protocols can be used (e.g. IETF RFC 2507, RFC 3095, RFC 4815). One instance of SNDC can be created per IP traffic flow.

Broadcast/Multicast Control (BMC) adapts broadcasting/multicasting data flows to the coverage area. It also manages services notification to the target audience that allows it to schedule the reception of a desired service.

Layer 2 Radio Tunnelling Protocol (L2RTP) provides tunnels for regenerative relaying, where the transmission format is not necessarily identical between reception and re-transmission. Due to potential multipath routing, an information block may be duplicated at a relaying node. L2RTP handles mechanisms to avoid unnecessary duplications.

SNDC, L2RTP and BMC belong to the User Plane.
All the layers that are described above make use of Radio Link Control (RLC) to transmit their PDUs to their peer entity.

RLC provides data transfer (either traffic or signaling) over one radio hop. It handles traditional Transparent, Unacknowledged and Acknowledged Modes. It thus manages several processes such as segmentation and reassembly, duplication detection and ARQ error correction. RLC support link re-establishment for temporary radio link suspension due to loss/recovery or Silent Mode. RLC can be configured to report transfer error rate to RRC. One RLC instance can be created per information flow.

Medium Access Control (MAC) schedules the physical medium in a real time manner and makes fast adaptation of the transmission format among the set of formats provided by RRC, on a frame per frame basis and according to several fluctuations such as source flow variations, discontinuous transmission (DTX) configuration, etc. MAC applies priority between flows from RLC. It also handles CSMA mechanisms or random access (depending on the scheme that is activated). MAC processes a survey of neighboring signals and reports to RRC (it is then up to RRC to activate message decoding for cooperation with route discovery implemented in RSN). MAC can be configured by RRC to report traffic/signaling quality and volume measurements. MAC implements timing advance with TDMA and/or OFDMA.

In addition of ciphering that may be done at the traffic source in the NAS, ciphering of signaling or data blocks can be done at the MAC/RLC level under control of the Security Plane.

The Physical layer (PHY) implements signal processing: modulation, channel coding and interleaving, CRC, optional physical level processing of Hybrid ARQ, bit and symbols scrambling. With CDMA it implements spreading and macro-diversity. In case of either CDMA or OFDM, it implements fast power control and MIMO processing. TRANSEC can be either implemented inside or outside PHY depending on the security architecture that is adopted.

Each layer implements peer-to-peer protocol and Protocol Data Units (PDUs) with the counter part located either at the neighboring node for the lower layers or at the multi-hop addressee node for the upper layers, as illustrated in Figure 4 (with the example of regenerative relaying in the user plane). Protocols and PDUs are potential candidates for standardization for multi-equipment interoperability while decision algorithms that optimize WBWF performance can remain proprietary. Service primitives could be standardized depending on the granularity that will be decided for SDR standardization.

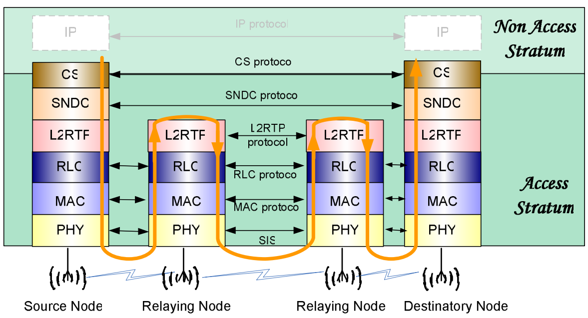

Figure 4 – Example of regenerative relaying Peer to peer User Plane protocol end points

3.4. Interworking with SCA platform

ETARE WBWF is compatible with standard implementation of SDR (SCA, APIs, …). For instance, it interacts with :

- OAM APIs for interface with the Management Plane,
- Security APIs for interface with the Security Plane,
- Location and synchronization APIs for interface with GNSS,
- Transceiver APIs for interface with the RF module,
- A set of application and data APIs for interface with upper layers from NAS i.e. inter network routing and traffic sources.

4. HANDLING FLAT AND/OR CLUSTERED NETWORKS

ETARE WBWF supports both flat and clustered routing. Hierarchical organization is also supported and a priori would be reserved for the ATH/NLI scenario. Dynamic transition between the flat mode and the clustered and hierarchical mode is ensured by reconfiguring of RRC and RSN without modifying the behavior of the architecture. An example with OLSR (ref. [4] and [5]) and HOLSR ref. ([6]) is given below. We can notice that OLSR can handle very large networks by using the fisheye extension (ref. [7]) or by using the hierarchical version of OLSR : HOLSR.

Depending on the current topology of the network, i.e. depending on the number of nodes in a given vicinity, nodes are able to take several roles :

- Member node i.e. an ordinary node whose RRC instance can be run in two modes :
  - In the absence of a Cluster Head within the vicinity : autonomous choice of radio resource in collaboration with MAC (flat configuration)
  - Else, slave mode i.e. radio resource usage is subservient to the Cluster Head it is attached to. RRC then implements the protocol messages for resource requests, allocation receipts and execution.
- Cluster Head : the RRC instance located in the Cluster Head implements the protocol and the algorithm for control and allocate of radio resources to other nodes. This is typically matched to OTM scenarios with the increase of node density.
- Gateway Node : making the interface between two or more clusters (and belonging to them),
- Cluster Head and Gateway Node : combination of both roles. This means adopting a hierarchical structure and is typically matched to ATH and NLI scenarios.

When the nodes switches from one role to another, RRC and RSN are dynamically reconfigured so that related algorithms and protocols are activated/inhibited accordingly.

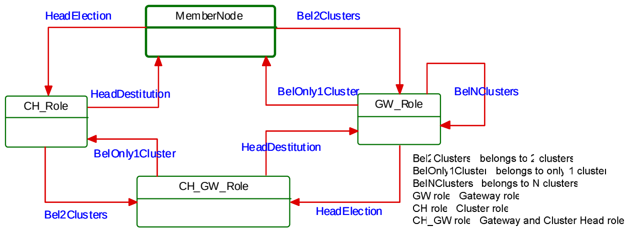

Figure 2 Node's Roles state transitions

When a Node is switched on, it initially has the basic Member Node role. RRC is in autonomous mode and activates PHY for signal reception for neighbor sensing. PHY is configured by RRC to report measurements associated to signal detection above a given threshold.

If nothing is detected, this means that potential neighboring nodes are transmitting at a too low a power level. Then RRC activates the sending of a signal with a power ramp up procedure (access probes procedure). The fact that transmission is made with power ramping is an alert to potential neighbor nodes that someone is trying to reach them, and thus they also increase their Tx power in a ramp up manner until they can be heard.

When a neighbor signal is detected, RRC configures and activates PHY, MAC and RLC for message reception and decoding.

A marker in the received message(s) indicates the role of the transmitter. If the transmitter is a Cluster Head, the Member Node RRC instance switches to slave mode. If not, it remains in autonomous mode. RRC indicates its status to RSN. The latter case is illustrated in Figure 6.

RSN activates the OLSR protocol and configures its algorithm in flat mode. Thus neighboring discovery is activated : HELLO messages are forwarded from PHY to RSN in the User Plane while measurements are reported from lower layers to RRC in the Control Plane. Branch messages are added to OLSR control messages as specified in ref. [7].

When a "number of neighbors"' threshold is reached (this threshold has been configured by OAM in the Management Plane, and has established minimum cluster size), this means that a procedure for clustering and Cluster Head election should be started by RSN.

If the node is elected then RRC instance transits to control state and thus is reconfigured with the related protocol and algorithm. If not, RRC instance goes to slave mode and is reconfigured to process protocol messages for resource request, allocation receipt and execution.

In both cases, a slow power control procedure is started at RRC level in order to limit Tx power i.e. to limit the coverage to a "maximum number of neighbors"' threshold (this maximum threshold has been configured by OAM in the Management Plane and has established the maximum cluster size).

The OLSR process for keeping neighbor knowledge up to date is continuously scheduled. PHY continues to report measurements to RRC for new signals detection.

For TDMA and/or OFDMA, adjacent clusters may either implement frequency sharing (with radio resource coordination) if the traffic is limited or, more often, implement a frequency reuse pattern higher than 3 (then the receiver implements multi-carrier scanning).

In both cases, when a Node detects that several received messages contain a flag indicating the transmitters are Cluster Heads, this means the node is under the coverage of two (or more) clusters and thus is a candidate to become a Gateway Node. Then the RSN reconfiguration algorithm should operate in accordance with the OLSR MPR selection algorithm.

Transition to hierarchical routing, i.e. centralization of the traffic flows to specific nodes, can be done in the same manner with the limitation that only authorized nodes such as ATH or naval nodes can be elected as root tree nodes. Reverting to non hierarchical clustered and flat modes is done according to a dedicated method.

In order to control clustering dynamics, a fast moving aeronautical node can not take the role of CH or GW (nor can it be an MPR of OLSR). This prohibition is managed by the RSN protocol layer via a protocol marker which indicates the nature of the node (vehicular, portable, slow or fast aeronautical, ATH, naval).

A slow moving aeronautical node such as a drone, due to its propagation conditions with ground terminals, is automatically selected as an MPR by OLSR (unless it would be configured by OAM as not eligible due to operational constraints). As such it is a natural candidate to GW between remote areas.

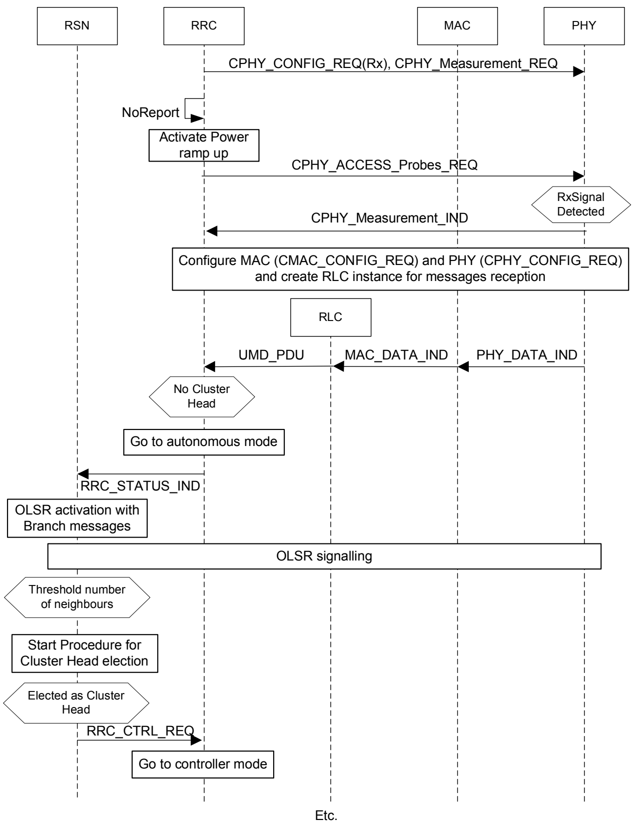

Figure 3 – Example of simplified inter-layer messages exchanges for transitions from flat network to clustering and hierarchical organisation together with routing

5. HANDLING OF MULTIPLE ACCESS SCHEMES

ETARE WBWF architecture enables several access schemes to be activated depending on the operational scenario in place. An example is developed hereafter : one can consider that OTM equipments are limited on the point of view of power consumption and antenna gain, and data rate. On the other side ATH and NLI equipments can benefit from higher antenna gain and support enhanced communication capabilities.

A typical use of multiple access schemes is as follows :

- OTM equipments transmit with hybrid TDMA/Single Carrier-(O)FDMA in low coverage conditions. An isolated and far away OTM equipment makes use of spreading to communicate with a Cluster Gateway i.e. DS-CDMA is applied over the TDMA/SC-(O)FDMA access scheme.
- ATH/NLI equipments communicate simultaneously with several OTM equipments. For a given TDMA slot they are able to receive from several FDMA carriers that have been synchronized at the OTM transmitter side in such a way that they are orthogonal at the ATH/NLI receiver (on the point of view of ATH/NLI, the received signal is TDMA/OFDMA like). Symmetrically, ATH/NLI transmitter is scheduled in a TDMA/OFDMA towards each TDMA/SC-(O)FDMA OTM receiver.

In OTM equipments, RRC implements algorithms for radio resources management in TDMA/SC-(O)FDMA and DS-CDMA modes. When an OTM equipment goes to ATH mode, the node goes to Cluster Head & Cluster Gateway mode and RRC is reconfigured to activate multi-carrier resource allocation algorithm. In the downlink direction (from ATH Cluster Head Node to OTM Member Nodes) it implements OFDMA by allocation one sub-carrier or one group of sub-carriers to OTM Member Nodes. In the uplink direction, the Cluster Head collects all the Single Carrier signals from OTM Member Nodes and combines them as OFDMA signal (on the point of view of Member nodes transmitters, signal is SC-OFDMA type while the ATH Cluster Head Node receiver has a view on multi sub carriers i.e. OFDMA).

RRC makes use of CPHY_CONFIG_REQ and CMAC_CONFIG_REQ inter-layer Control Plane primitives to reconfigure MAC and PHY accordingly. An NLI equipment does not switch from one mode to another thus its RRC entity is configured at initialisation (power on) (contrarily to mobile terminal equipped with a gain mast antenna that can switch from OTM to ATH mode and vice versa and for which ETARE WBWF architecture enables dynamic reconfiguration).

6. HANDLING OF MIMO

ETARE WBWF architecture is compliant with the handling of MIMO for individual radio links as well as for cooperative multi-links MIMO (Multi-User MIMO).

Due to tight synchronization and power control constraints, MU-MIMO may be reserved to those scenarios :

- where the Cluster Head is stable and plays the roles of traffic concentrator as a Cluster Gateway i.e. ATH and/or NLI scenario or
- in high density areas, to unload Cluster Gateways (load balancing feature).

We take hereafter the example of portable terminals operated in the 225-400 MHz band (wavelength is 75 cm to 133 cm). Then OTM Member Nodes portable configurations are equipped with single antenna while ATH/NLI Node can be equipped with antenna array.

Cluster Head RRC entity is configured with MU-MIMO decision algorithm. It periodically receives quality measurements from lower layers as well as measurement reports from Member Nodes. This centralized RRC entity supervises power control of Member Nodes and thus has a knowledge of Member Nodes actual transmit power. When it detects received quality degradation and Member Nodes Tx power leakage, it can decide MU-MIMO activation i.e. ordering a set of Member Nodes to transmit a given information flow on the same radio resource. At the Cluster Head there is coordination between RSN and RRC for this cooperating transmission. The Cluster Head RRC configures its RLC, MAC and PHY layers and sends signalling RRC messages to the Member Nodes that are involved, including switching time to cooperative transmission.

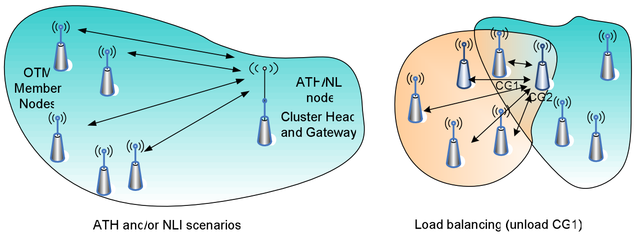

Figure 4 – MU-MIMO for ATH/NLI scenarios or high density OTM clusters

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