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Research Article

Converged Wireless Networking and Optimization for Next Generation Services

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The Next Generation Network (NGN) vision is tending towards the convergence of internet and mobile services providing the impetus for new market opportunities in combining the appealing services of internet with the roaming capability of mobile networks. However, this convergence does not go far enough, and with the emergence of new coexistence scenarios, there is a clear need to evolve the current architecture to provide cost-effective end-to-end communication. The LOOP project, a EUREKA-CELTIC driven initiative, is one piece in the jigsaw by helping European industry to sustain a leading role in telecommunications and manufacturing of high-value products and machinery by delivering pioneering converged wireless networking solutions that can be successfully demonstrated. This paper provides an overview of the LOOP project and the key achievements that have been tunneled into first prototypes for showcasing next generation services for operators and process manufacturers.

1. Introduction

The NGN vision is tending towards a diverse wireless networking world where scenarios define that the user will be able to effectively attain any service, at any time on any network that is optimized for the application at hand. An important architectural issue is that of defining a next-generation wireless system, which acts as a "network-of-wireless-networks" accommodating a variety of radio technologies and mobile service requirements in a seamless cost-effective manner. The convergence of internet and mobile services is currently being addressed by the IMS (IP Multimedia Subsystems) platform, driven mainly by the operators and service providers to address market opportunities in combining the appealing services of internet with the roaming capability of mobile networks. But this convergence does not go far enough, and with the emergence of new coexistence scenarios, there is a clear need to evolve the current architecture to provide cost-effective end-to-end communications. This will raise significant research challenges and, undeniably, system coexistence solutions to address WAN (Wireless Area Networks), and LTE (Long-Term Evolution RAN) interoperability (Figure 1), and their impact on the 3GPP SAE (System Architecture Evolution) and IMS architectures require further innovation to align with future wireless trends and deliver new market opportunities for all players in the supply chain.

Under the umbrella of converged services and networks, LOOP technology is targeting potential applications in the wireless market for process manufacturing. This market is expected to grow at a pace neighbouring 30% per year; faster than the wired contingent. Nevertheless, adoption of wireless technology is still low and most managers are reluctant to introduce radio solutions; key impediments being latency and performance issues. In LOOP, these challenges have been addressed for delivering virtual metrology services in the automotive industry as a case study.

In this paper, we provide an overview of the main achievements emanating from the LOOP project (EUREKA-CELTIC call 4: an instrument that aims to strengthen Europe's competitiveness in telecommunications through short- and medium-term collaborative R&D projects) that have led to potential innovative products for operators and wireless process manufacturers. This paper is organized as follows: Section 2 presents the LOOP case studies and the associated technical challenges; Section 3 provides an overview of the key technical achievements; Section 4 presents the product innovations born from LOOP; the conclusion is in Section 5.

2. LOOP Scenarios and Technical Challenges

In order to better understand the technical challenges faced by the convergence of wireless networks, herein we provide the description of the two major scenarios identified within the scope of the project targeting the telecoms industry and process manufacturing.

The first scenario targets potential new services and energy-efficient networks for the operators in order to anticipate the deployment of NGNs in an era where spectral resources are at premium. The deployment of NGN aims at a global infrastructure where several systems can coexist to support transparent end-to-end communications in a cost-effective manner. An important issue for next generation wireless systems will be coexistence and optimization to provide a "network-of-wireless networks" accommodating a variety of radio technologies and mobile services in a seamless and cost-effective manner. To address these issues, the main focus of LOOP was to explore innovative solutions targeting the following.

(i) Network discovery, session management and roaming allowing the end-user to maintain session continuity whilst roaming between operators and heterogeneous wireless technologies.

(ii) Ad-Hoc networking for relay-based cell coverage extension to extend wireless and mobile coverage providing enhanced QoS delivery and extended service delivery to remote and fringe users.

(iii) Dynamic spectrum allocation for heterogeneous networks to investigate the opportunistic use of licensed spectrum by secondary systems for optimized utilization of scarce spectral resources.

(iv) Intra-system optimization to maximize network utilization by exploring the application of a cross-layered protocol architecture.

The second scenario is directed towards the car manufacturing industry and focuses on the deployment of metrology services on the factory floor to allow quality control production engineers to analyze and process large volumes of 3D multimedia information in real-time anywhere and anytime, as shown in Figure 2.

A major problem for manufacturing companies is the maintenance of their cost-intensive, production-critical assets, such as machines, tools, and equipment. These assets constantly suffer from aging and wear, which often lead to functional loss and breakdown of machines, and ultimately, complete standstill of production with costly consequences. One promising approach is to anticipate and address the problems before they occur. The LOOP project provides a solution for ubiquitous monitoring and management of Coordinate Measurement Machines (CMM) based on closed-loop approaches through wireless and nomadic sensors placed around the mechanical robot in a car production line. The LOOP application would inform the maintenance engineering team of potential problems in order to ensure their prevention and to manage their repair with a sustainable plan in mind. The targeted solution is based on the need for NGN solutions enabling physical and semantic interoperability of required sensors, devices, services and systems. LOOP builds on relevant ongoing progress in wireless routing protocols based on cross-layer design to ensure that a fast and proactive communication path is established on the factory floor back to a Maintenance Service Centre (MSC)/Central Decision Point (CDP) in order to mobilize the resources for repair or to stand by for further updates and information.

3. LOOP Achievements

3.1. Suitability-Based RAT Selection Algorithm. Networks of the future will explore cooperative platforms in a bid to provide cost-effective communications to the end user. In a bid to address this challenge, interworking architectures have been proposed by ETSI/BRAN [1] and 3GPP [2] such as the loose and tight coupling approach for WiFi and UMTS/HSDPA (High-Speed Downlink Packet Access). Moreover, several solutions have been proposed within international research projects that worked on architectures and platforms for cooperation schemes between heterogeneous Radio Access Networks (RANs) [3–6], mainly focusing on interworking architectures between UMTS/HSDPA and WiFi. In [7], the requirements and algorithms for cooperation of several RANs are presented. Cooperation can also be

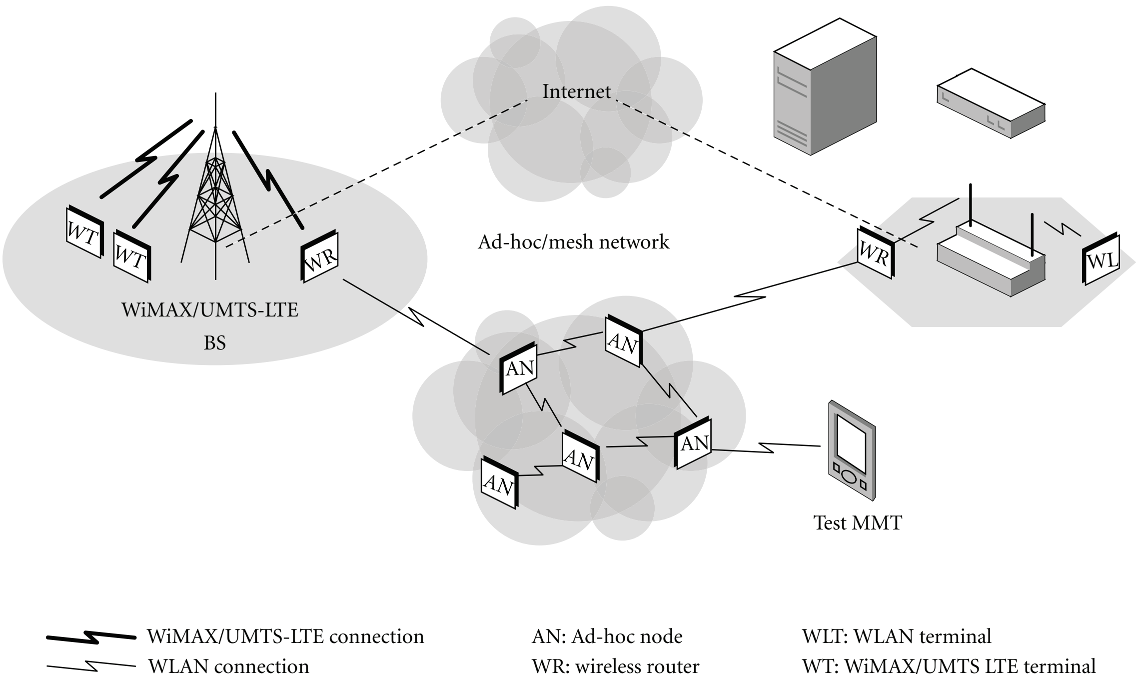

Figure 1: LOOP scenario.

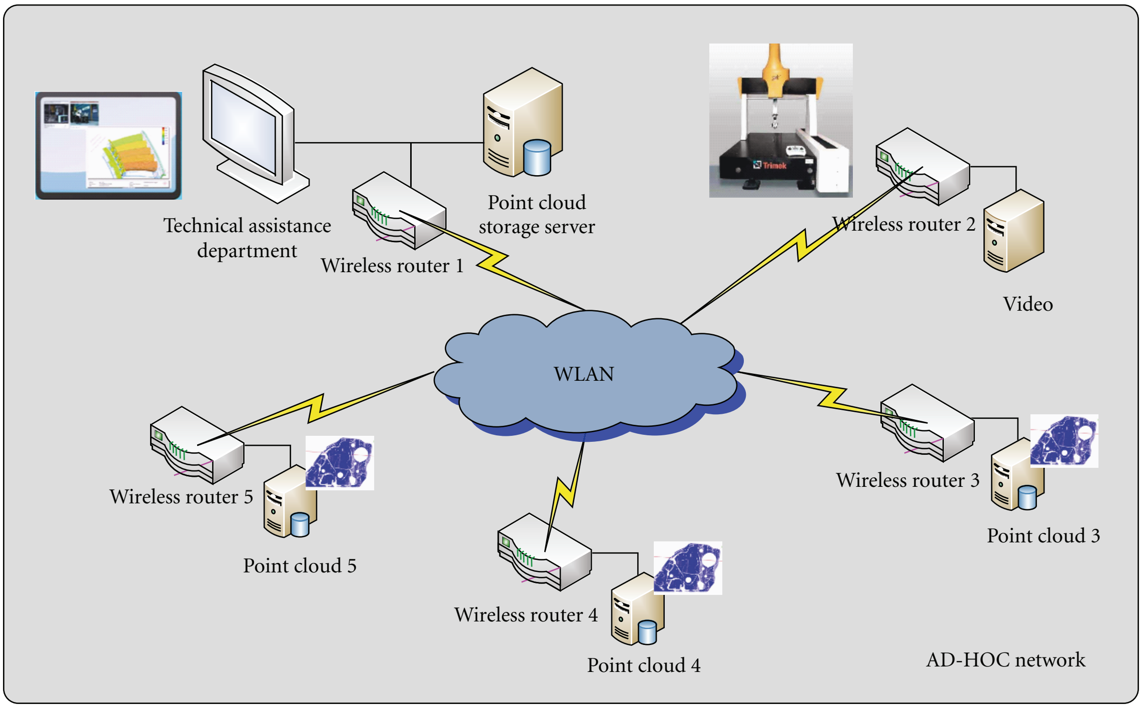

Figure 2: TRIMEK scenario.

achieved by means of a CRRM (Cooperative Radio Resource Management Entity) entity that is able to direct traffic through different networks according to operator-specific requirements and based on cross-system information. More specifically, the CRRM is responsible for (i) gathering system- and user-specific information, (ii) processing this information according to operator specific criteria, and (iii) triggering a new handover event according to the load balancing criteria and position. It is assumed that either a common operator deploys both systems or the system operators share a service-level agreement (SLS). Reference [8] investigated a CRRM-type cooperation based on the load-suitability for delay-constrained services. The notion of suitability is based on the most preferred access system to accommodate the service, but the suitability factor can change as load increases in order to maintain the quality of service across the networks. In LOOP, we extend this notion of suitability cooperation for RAT (Radio Access Technology) selection to optimize the choice between WiFi and HSDPA.

The suitability cooperative algorithm for RAT selection is expressed by

$$S\left(\mathrm{L}\left(\mathrm{cell}_{i,j}\right)\right) = \begin{cases} 1, & \text{if } \mathrm{L}\left(\mathrm{cell}_{i,j}\right) \le \mathrm{LTh}_j, \\ \left(\dfrac{1-\mathrm{L}\left(\mathrm{cell}_{i,j}\right)}{1-\mathrm{LTh}_j}\right)^2, & \text{if } \mathrm{L}\left(\mathrm{cell}_{i,j}\right) > \mathrm{LTh}_j, \end{cases} \qquad (1)$$

where $\mathrm{cell}_{i,j}$ represents the cell/AP i pertaining to RAT_j; $\mathrm{L}(\mathrm{cell}_{i,j})$ is the normalized load in $\mathrm{cell}_{i,j}$; LTh_j is the load threshold for RAT_j; $S(\mathrm{L}(\mathrm{cell}_{i,j}))$ is the suitability value for accepting a new user in $\mathrm{cell}_{i,j}$.

The algorithm was testing the use-case scenario involving HSDPA partially overlapped by WiFi indoor hotspots, assuming high-priority NRTV (Near Real-Time Video) traffic at 64 kbps characterised by the 3GPP model [9]. Figure 3 provides the simulation results for CRRM goodput (bits that are received correctly and within the QoS delay threshold) versus offered load.

LOOP results show that the CRRM system throughput gain introduced by service suitability is significant and sensitive with regards to the service suitability threshold. The optimal load threshold was determined to be $\mathrm{LTh}_0 = 0.6$ where the potential observable gain is around 1.2 Mbps in contrast to the stand-alone HSPDA scenario; the use of smaller load thresholds is not advised, since it causes the WiFi system to overload faster-causing problems to the existing background traffic.

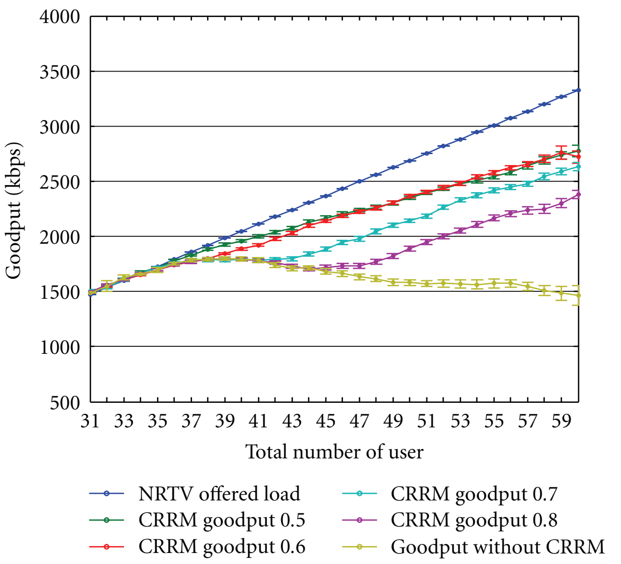

FIGURE 3: System total throughput with CRRM entity exploring the diversity gain for cell radius = 50 m.

3.2. Ad hoc Networking for Relay-Based Cell Coverage Extension. In the LOOP project, we have studied mechanisms to extend the cell coverage through cooperative mechanisms based on the use of relays. In particular, we have focused on Cooperative Automatic Retransmission Request (C-ARQ) schemes [10] which allow for the transmission of data even when the channel conditions are poor, and errors are frequent, by enabling spontaneous relays to retransmit upon the occurrence of a transmission error from the source. In LOOP, we have designed a new MAC protocol to coordinate the retransmissions from these helpers or relays called Persistent Relay Carrier Sensing Multiple Access (PRCSMA) protocol, and it represents an extension of the IEEE 802.11 Standard [11] to operate in C-ARQ schemes. A comprehensive description, theoretical analysis, and performance evaluation of the protocol can be found in [12]. When using PRCSMA, all the stations must listen to every ongoing transmission in order to be able to cooperate if required. Whenever a data packet is received with errors at the destination station, a cooperation phase can be initiated by broadcasting a Call for Cooperation (CFC) packet. Upon the reception of the CFC, all the stations willing and able to cooperate become active relays and get ready to forward the original packet. To do so, they use the MAC rules specified in the IEEE 802.11 Standard [11] considering the two following modifications.

(1) There is no expected ACK associated to each transmitted cooperation packet.

(2) Those active relays which do not have an already set back-off counter (from a previous transmission attempt) set it up and initiate a random back-off period before attempting to transmit for the first time. Those relays which already have a non-zero back-off counter value keep the value upon the initialization of a cooperation phase.

A cooperation phase is completed, either when the destination station is able to decode the original data packet by properly combining the different retransmissions from the relays, or when a certain maximum cooperation timeout has elapsed. In the former case, an ACK packet is transmitted by the destination station. In the latter case, a negative ACK (NACK) is transmitted by the destination station. In any case, all the relays pop out the cooperative packet from their queue upon the end of a cooperation phase.

The performance of PRCSMA has been analytically modeled by applying Markov Chain Theory [12]. We have focused on the evaluation of the average packet transmission delay when cooperation is required, which is defined as the average amount of time elapsed from the moment a packet is transmitted for the first time until it can be decoded without errors at the destination upon the reception of an arbitrary number K of retransmissions received from the relays.

We plot in Figures 4 and 5 the value of the average packet transmission delay for the case when the relays can

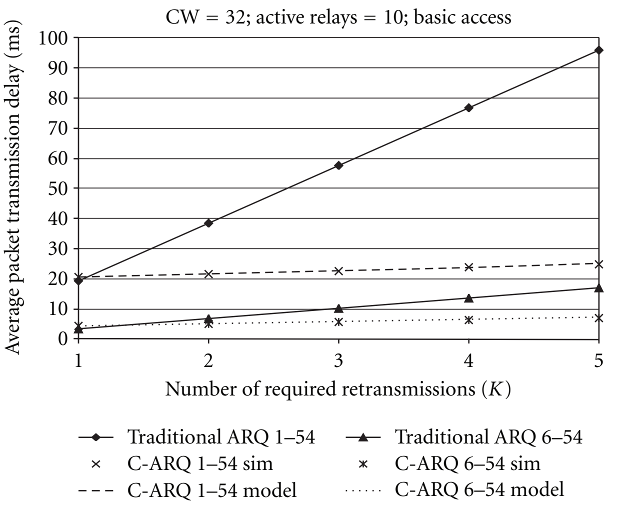

Figure 4: Average Packet Transmission Delay (relay low rate regime).

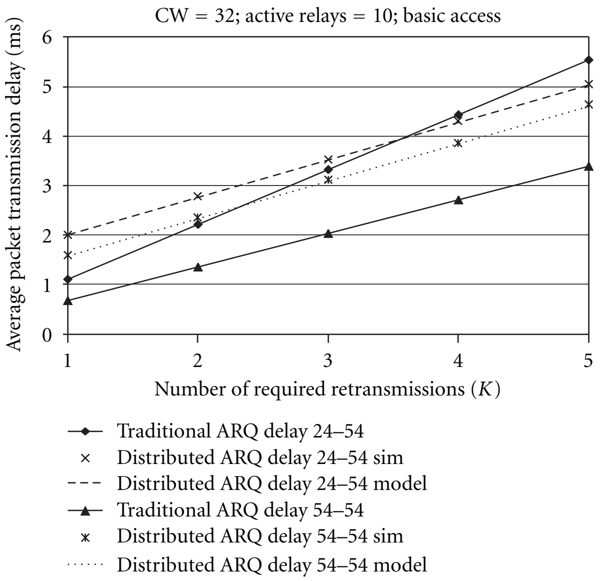

Figure 5: Average Packet Transmission Delay (relay high rate regime).

transmit at 54 Mbps to the destination while the source can do it at 1, 6, 24, or 54 Mbps. The data transmission rates are represented in the legend of the plots indicating the transmission rate of the source and the transmission rate of the relays separated by a dash. The control transmission rate has been fixed in all cases to 6 Mbps. In addition, we consider in all cases that the C-ARQ is executed by means of the PRCSMA basic access, that is, without RTS/CTS handshake. The traditional ARQ curve represents the case when the retransmissions are only requested from the original source (there are no relays). Finally, it is worth mentioning that we have included in the plots both the results obtained through computer simulation and by means of the derived theoretical model. The perfect match between the two cases shows the accuracy of the developed model.

The ratio between the transmission rate of the source and that of the relays determines how efficient the C-ARQ mechanism is in comparison to the traditional non-cooperative ARQ approach, where the retransmissions are only requested from the source at the best available transmission rate between the source and the intended destination station and without contention between consecutive retransmissions. For example, in the case of using the transmission rate set 1–54 (source-relays transmission rate), when $K = 5$, the C-ARQ reduces the average packet transmission delay by a factor 4 compared to the traditional ARQ scheme. On the other hand, at the limit where the relay stations transmit at the same rate as the source station, the average delay in the C-ARQ scheme is higher due to the cost of coordinating the set of relays.

It is worth mentioning that, as can be expected, if K is very low, then the efficiency of the C-ARQ scheme becomes similar to that of a traditional non-cooperative ARQ scheme. This is due to the fact that, despite the faster relay retransmissions, the overhead associated to the protocol does not pay off the reduction of the actual data retransmission time. In the case of networks where the data transmission rate of each station is selected as a function of the channel state between source and destination stations, as in IEEE 802.11 WLANs, the behavior of PRCSMA shows that C-ARQ schemes would be especially beneficial for those stations located far away, in radio-electric terms, that is, at the cell boundaries from a transmitting station. Note that these stations will be prone to transmit at very low transmission rates and therefore they could benefit from faster and more reliable retransmissions performed by intermediate relay stations on the path from the source station. In addition, the whole network, that is, the rest of the stations, will benefit from this scheme in the sense that faster transmissions will occupy the channel for shorter periods of time.

3.3. Cooperative Spectrum Sensing for Cognitive Radio-Enhanced Heterogeneous Networks.

As wireless technologies continue to grow, more and more spectrum resources will be needed. However within the current spectrum regulatory framework, all of the frequency bands are exclusively allocated to specific services, and no violation from unlicensed users is allowed. A recent survey of spectrum utilization made by the Federal Communications Commission (FCC) has indicated that the actual licensed spectrum is largely underutilized in vast temporal and geographic dimensions [13].

Spectrum utilization can be improved significantly by allowing a Secondary User (SU) to utilize a licensed band when the Primary User (PU) is absent. Cognitive Radio (CR), as an agile radio technology, has been proposed to promote the efficient use of the spectrum [14]. By sensing and adapting to the environment, a CR is able to fill in spectrum holes and serve its users without causing harmful interference to the licensed user. To do so, the CR must continuously sense the spectrum it is using in order to detect the reappearance of the PU. Once the PU is detected, the CR

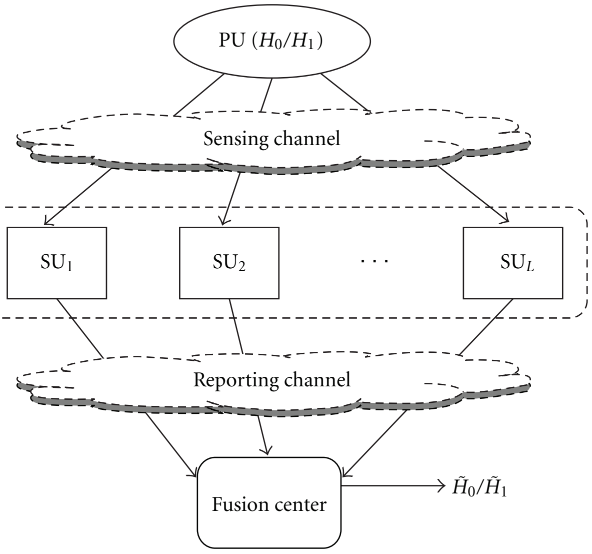

FIGURE 6: Multilayer distributed/cooperative spectrum sensing.

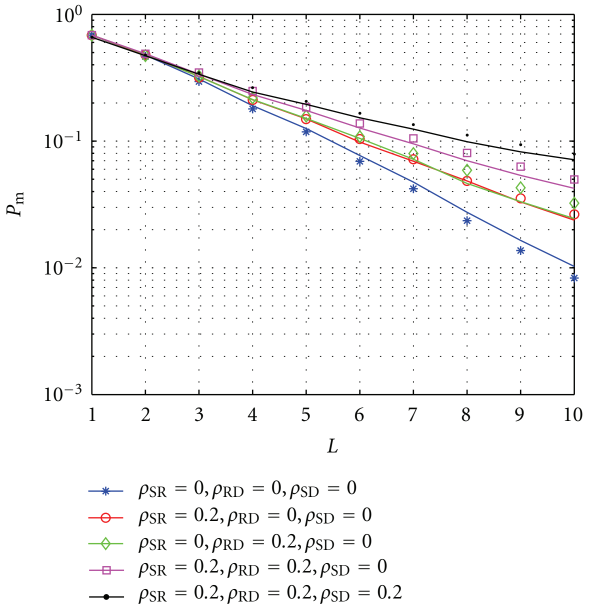

FIGURE 7: Probability of not detecting a PU (P_m) against the number of cooperating CRs (L). The curves are obtained for different values of the correlation coefficient of the shadow fading over the sensing channel (ρ_{SR}), the reporting channel (ρ_{RD}), and pairs of links on the sensing and reporting channels (ρ_{SD}).

should withdraw from the spectrum so as to minimize the interference it may possibly cause. However, a very important challenge of implementing spectrum sensing is the hidden terminal problem, which occurs when the CR is shadowed, in severe multipath fading or inside buildings with a high penetration loss while a PU is operating in the vicinity.

Cooperative communications are an emerging and powerful solution that can overcome the limitation of wireless systems [15]. The basic idea behind cooperative transmission rests on the observation that, in a wireless environment, the signal transmitted or broadcast by a source to a destination node is also received by other terminals. These latter nodes can process and retransmit the signals they receive. The destination then combines the signals coming from the source and the partners, thereby creating spatial diversity by taking advantage of the multiple receptions of the same data at the various terminals and transmission paths.

By allowing multiple CRs to cooperate in spectrum sensing, the hidden terminal problem can be addressed [16]. Indeed, cooperative spectrum sensing in CR networks has an analogy to a distributed decision in wireless sensor networks, where each sensor makes a local decision and those decision results are reported to a fusion centre to give a final decision according to some fusion rule. The main and fundamental difference between these two applications lies in the wireless environment. Compared to wireless sensor networks, CRs and the fusion centre (or common receiver) are distributed over a larger geographic area. This difference brings out a much more challenging problem to cooperative spectrum sensing because sensing channels (from the PU to CRs) and reporting channels (from the CRs to the fusion centre or common receiver) are normally subject to fading or heavy shadowing.

In LOOP [17], we have analyzed, for the first time in the literature, the fundamental problem of cooperative spectrum sensing over wireless environments characterized by realistic propagation conditions, that is, heavily and spatially correlated shadowing environments. More specifically, we have proposed an advanced framework for performance analysis and optimization of a general multilayer decentralized data fusion problem for application to cooperative spectrum sensing, which includes realistic sensing/reporting channels and correlated Log-Normal shadowfading in all wireless links of the cooperative network. The analyzed system setup is sketched in Figure 6.

The analysis of the scenario in Figure 6 has revealed an important result: even though always overlooked in typical cooperative spectrum sensing analysis, shadowing correlation on the reporting channel can yield similar performance degradations as shadowing correlation on the sensing channel. So, our performance study has revealed that further importance should be given to the role played by the reporting channel for a sound analysis and design of distributed detection problems with data fusion, especially when the system is expected to be deployed in realistic propagation environments targeted for CR applications. An example of the obtained results is shown in Figure 7.

3.4. Cross-Layer Packet Scheduling for WiMAX. The IEEE 802.16 standard [18, 19] provides specification for the Medium Access Control (MAC) and Physical (PHY) layers for WiMAX (Worldwide Interoperability for Microwave Access). A critical part of the MAC layer specification is the scheduler, which resolves contention for bandwidth and determines the transmission order of users; it is imperative for a scheduler to satisfy QoS requirements of the users, maximizing system utilization and ensuring fairness among the users. The basic approach for providing the QoS guarantees in the WiMAX network [20, 21] considers that the BS performs the scheduling for both the uplink and downlink directions; an algorithm at the BS has then to translate the QoS requirements of SSs into the appropriate number of slots.

The IEEE 802.16d/e standards [18, 19] do not specify scheduling techniques for MAC layer in WiMAX networks, and the existing NS-2-based simulation platforms [22], implement only QoS-aware scheduling based on Service class prioritization. We propose a simple, efficient solution for the WiMAX scheduler that is capable of allocating slots based on the QoS Service class, traffic priority and the WiMAX network and transmission parameters. To test the proposed solution, the QoS model for the IEEE 802.16d/e MAC layer in the NS-2 simulator [23] developed by the WiMAX Forum [22, 24, 25] was taken as a reference.

We propose the Enhanced Round Robin (eRR) scheduler (cf. Figure 8). It is based on the simple round robin solution, but introduces more elements in the decision-making process for packet allocation within each radio frame.

The proposed scheduler algorithm has in fact two objectives.

(i) The first, that was already mentioned, maps the user traffic to the available radio resources according to the service class and radio channel quality.

(ii) The second allows user differentiation/priority within each service class and thus enables the network operator to implement new business models, the concept of gold, silver and bronze users, guaranteeing at the same time the subscribed QoS.

In practice, the algorithm initially performs the same round robin procedure as explained in the previous models, that is, serving first connections in the following order: UGS, rtPS, nrtPS, and BE. From the list of existing connections inside the same class, a priority is also established taking into account the RSSI (Received Signal Strength Indication) value for the given node; where highest priority is given to users with highest signal strength. This approach will provide a trade-off between optimizing spectral efficiency and guaranteeing QoS.

Simulations were realized using a point-to-multipoint topology with three services running on the same terminal, conveying differentiated traffic in the uplink direction, namely, the configured traffic sources for UGS (Unsolicited grant service), rtPS (Real time polling service) and BE (Best Effort). In this scenario, we have defined the relevant PHY layer simulation parameters. The key simulation parameters are summarized in Table 1.

Figure 9 shows the slight gain difference that can be achieved in throughput using the enhanced Round Robin solution, in contrast to the observed earlier service class differentiation. In this particular case, the traffic priority was assumed to be equal among the same classes, the priorities here are based on the service class and RSSI of the respective terminal.

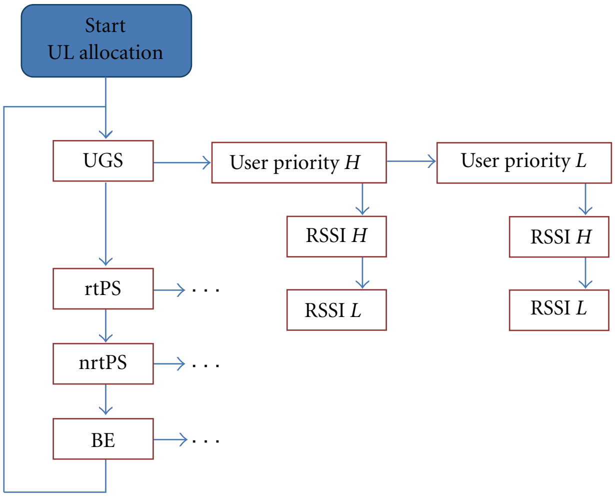

FIGURE 8: Enhanced Round Robin algorithm.

TABLE 1: Simulation parameters.

Metric		Quantity
Frequency		3.493 GHz
Bandwidth		20 MHz
Frame duration		5 ms
Downlink ratio		0.3
Modulation		16 QAM
Channel model		Cost 231
Fading model		ITU_PDP_PED_A
Cyclic prefix		0.25
Queue length		100 packets
	Services Parameters	
Traffic type	Bit rate (kbps)	Packet size (bytes)
BE	200	512 to 1024
UGS	200	300
rtPS	200	200 to 980

Concerning delay, as shown in Figures 9 and 10, the proposed scheduler reduces the overall packet delay and either equals or slightly outperforms the existing Round Robin based on the WMF (WiMAX Forum) model.

Figures 11 and 12 illustrate the scenario consisting of terminals supporting the rtPS and BE classes, respectively, and different traffic priorities inside each service class, that is, rtPS1 has lower priority than the rtPS connection and BE1, also in respect to BE. The results show the priorities in the scheduling decision as both classes are distinguished in terms of throughput and delay (better values are observed for rtPS classes than BE ones) and traffic prioritization inside each particular class (improved performance for rtPS and BE in relation to rtPS1 and BE1, resp.).

In Summary, the eRR algorithm provides a new innovative scheme to implement new business models based on the application of the cross-layer paradigm for RR scheduling. Numerical results show that the proposed scheme can

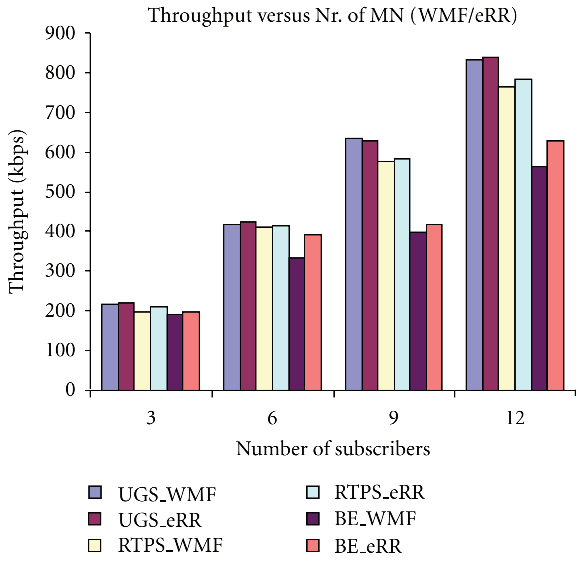

Figure 9: Throughput RR/eRR.

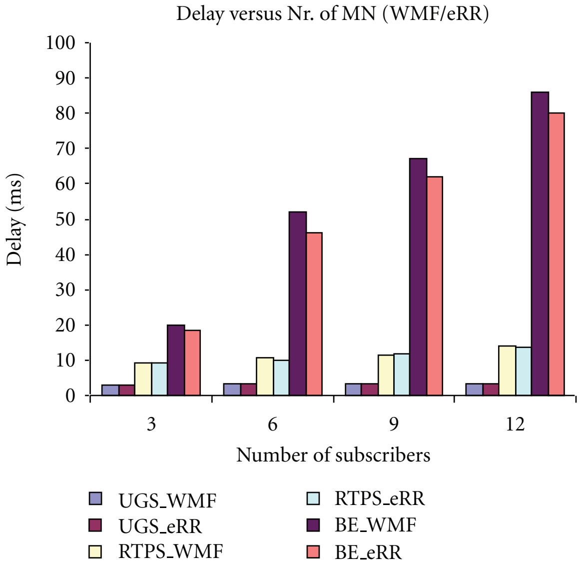

Figure 10: Delay RR/eRR.

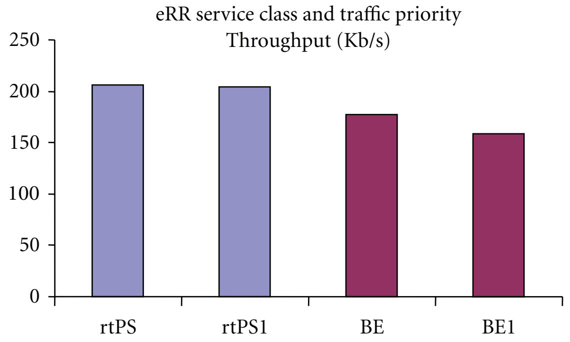

Figure 11: Throughput.

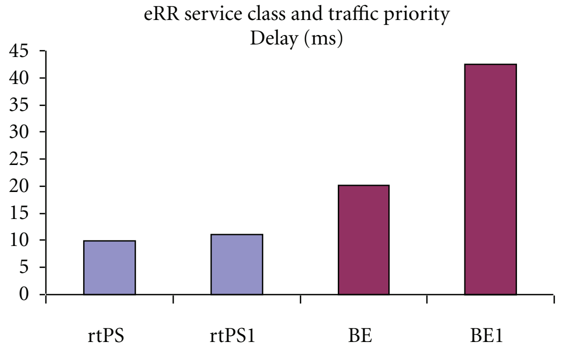

Figure 12: Delay.

increase the system throughput by up to 11%, reduce traffic delay by 27%.

3.5. Cross-Layer Optimized Routing Strategies. The benefits of cross-layer system design are mainly being applied in the area of mobile and wireless operators. In recent years, the area of communications in the manufacturing process is gaining importance. Traditional Ethernet and PROFIBUS [26, 27] factory systems are being enhanced to facilitate new means of automation through attractive wireless solutions: to provide added flexibility and self-configuration in processing machines to reduce production costs. LOOP tackles machine automation by investing communication challenges related to remote management of Coordinate Measurement Machines (CMMs) for future manufacturing environments. Specifically, we aim to investigate routing strategies to provide fast and efficient data management on the factory floor that is highly dynamic in nature. LOOP specifically addresses cross-layer enhancements to both flat and hierarchical routing strategies.

In HOLSR (Hierarchical Optimized Link State Routing), there are two levels of hierarchy according to our network design as shown in Figure 13, where Level-1 hierarchy corresponds to connection among backbone network nodes, while Level-2 hierarchy corresponds to connection among mesh routers in access networks.

Regarding the second cross-layer enhancement, Cross Layer Link Layer Notification, the basis is to utilize link break information gathered at the MAC layer to impose OLSR [28] routing table recalculation. More specifically, the MAC layer detects the link break and sends an indication to the protocol layer. Upon receiving such an indication which is treated as a topology or neighbor change, OLSR conducts routing table recalculation immediately. Finally, note it is of great importance to understand which approach is more effective, namely, cross-layer or hierarchical, to deploy the correct solution based on the dimension addressed.

Simulation results (Figure 14) provide the performance of video communication over the network, as the transmission of the virtual part was taking place. Such multimedia stream would be directed to experts in assisting the manufacturing decisions all over the plants that are normally very

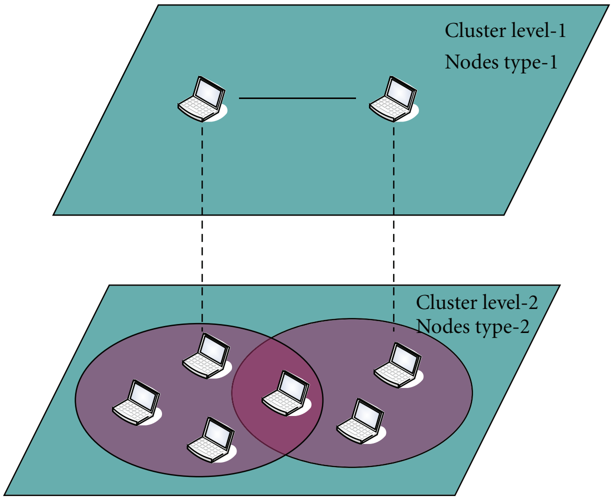

FIGURE 13: Hierarchical network design.

large. The video connection has a bit rate of 128 kbps and a QCIF format.

The results obtained suggest that in small deployment areas, intrasystem optimization based on cross-layer approaches is more effective than the hierarchical counterparts.

4. LOOP Products

Carrying out research at European level is primarity important when facing the global market, since gaining knowledge on novel technologies and system integration may provide the needed competitive advantage at industrial level, that is, better European products or better European-based networks deployed around the world. In this context, LOOP has transferred engineering know-how to meet the short-term market requirements to allow industry to anticipate the commercial deployment towards NGNs in terms of delivering potential products that include the following.

OptiMaX (Portugal Telecom Inovação). Radio access network planning and deployment is a complex process that can be divided into two key stages. In this first stage, the optimization goals (capacity, coverage and QoS) are defined, the network is dimensioned and the radio planning and optimisation loop are initialized. In this process, sophisticated planning and optimisation tools are used which resort to complex cost functions to perform various trade-offs. The output from the iterative optimization stage results in BS parameters corresponding to the Radio Resource Management (RRM) algorithm under test. In the second stage, after network deployment, network performance and quality characteristics are monitored. In this stage, monitoring tools are used to collect the geo-referenced radio measurements (e.g., SNR) in order to evaluate the difference between what was planned and what is in fact implemented. Based on monitoring results and on the RNP (Radio Network Planning) simulations, the radio network parameters are tuned which usually include both hard (e.g., antenna tilts) and soft parameters (RRM mechanisms).

Despite the widespread deployment of WiMAX (IEEE 802-16d) networks, there is no radio monitoring tool on the market to support network operators in the optimization task; hence this provided the impetus for the OptiMax tool proposed in the scope of the LOOP project.

OptiMax is a new tool that allows the network operator to perform network analysis and planning for the WiMAX (IEEE802.16d) system. The monitoring phase not only constitutes collecting and storing the radio signal quality for coverage measurements, but can also “sniff-out” essential network information pertaining to the IEEE802.16 protocol. Moreover, the monitoring capabilities of the tool can also estimate the maximum bit rate per location for a particular bandwidth.

In order to obtain this network-related data, specific CLI (Command-Line Interface) requests are made to the SS (Subscriber Station). The replies are parsed to XML format resultant from the monitoring phase. Each monitoring session is attached with the potential locations of each WiMAX Base Station so that it can be overlaid on a geographical map, where each position is represented by a coloured circle ranging from red (low RSSI, Received Signal Strength Indication) to green (higher RSSI).

The hardware needed to execute each test is shown by Figure 15. It constitutes:

(1) laptop, with OptiMax application installed, for mobility testing,
(2) GPS system, the used GPS system connects via Bluetooth,
(3) WiMAX omnidirectional antenna,
(4) UPS system and a PoE (Power over Ethernet) unit providing energy for the SS,
(5) a WiMAX SS (Subscriber Station), connected to the laptop using an Ethernet cable.

The equipment used, was chosen by its flexibility, low cost and easy loading in an automobile for field testing.

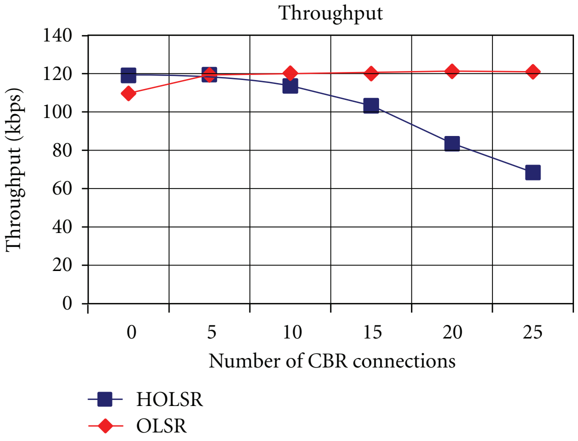

FIGURE 14: Throughput—Hierarchical OLSR versus enhanced OLSR.

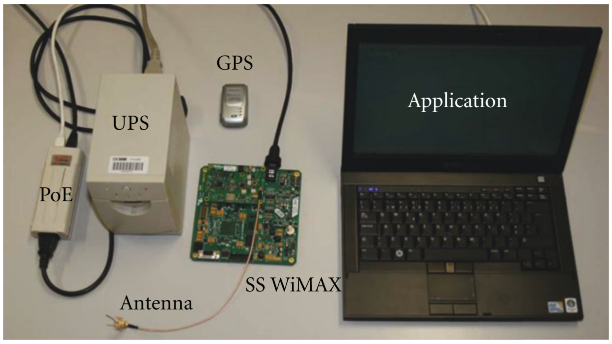

Figure 15: Portugal Telecom Inovação's OptiMax tool.

The OptiMax tool collects the geo-referenced radio measurements (e.g., SNR) in order to evaluate the difference between what was planned and what is in fact implemented. Based on the monitoring results and on RNP (Radio Network Planning) tool simulations, the radio network is optimized: antenna tilts and azimuth, transmitted power level, and so forth.

WiMAX System Experimental Platform (Turkcell). Mobile WiMAX is an access technology that promises high-data rates and wide coverage at low cost. Mobile WiMAX is based on 802.16 2009 which specifies the air interface including the physical layer (PHY) and medium access layer (MAC) for broadband wireless systems. To achieve high throughput and very good spectral efficiency, mobile WiMAX combines orthogonal frequency division multiple access (OFDMA) and multiple input multiple output (MIMO) with link adaptation and hybrid automatic repeat request (ARQ) algorithms. However, wireless communication technologies, and how to exploit better spectral efficiency improve day-by-day. Toward this end, we were interested in developing the WiMAX system level simulator to act as an experimental platform to test new algorithms/protocols for enhancing system efficiency through augmenting cell capacity. The main challenges in the implementation of such a simulator were the selection of parameters and assumptions.

To overcome this challenge, we developed a system-level simulator compliant with the 802.16 m Evaluation Methodology [29]. The simulator test-bed was validated for different network configurations such as antenna numbers, frequency reuse patterns, user densities, and mobility of users.

Management Tools for Wireless Process Manufacturing (TRIMEK). The wireless market in Process Manufacturing is expected to grow at a pace neighbouring 30% per year. It is growing faster than wired market. Nevertheless, adoption of wireless technology is still very low and most of managers in industry are reluctant to introduce radio solutions when wired alternatives exist. The primary impediments to wireless penetration are latency and performance issues, as well as reliability and security of sensitive information. In the scope of LOOP, these challenges have been addressed by applying autonomous wireless networks with cross-layer routing strategies to provide remote management capabilities for the flexiblity and self-configuration of measurement machines.

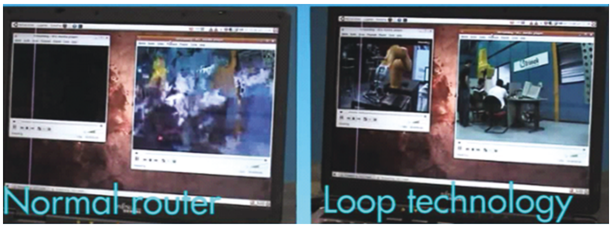

Figure 16: Router performance before versus after LOOP technology.

Remote management is a key business opportunity for process manufacturers to provide technical assistance towards the offering of complete automation solutions allowing industrial automation and control providers, as well as major system integrators, to manage or visualize complete and self-contained control components, including software-based functionality, command and control, configuration, diagnostics, and documentation. TRIMEK is a CMM manufacturer, as well as a service provider for this kind of machinery. These are complex systems composed by a large number of parts (mechanical, electrical, electronic, IT, etc.). Therefore, any service regarding them might require the knowledge of professionals from different fields. Unfortunately it is not possible to forecast in advance the needs of both the machine and the service demanded by the client. For this reason, the help of new technology in this field will have the potential to provide an internal tool to satisfy unexpected problems in a short-time basis and with the accuracy required by this type of systems.

The role of LOOP has been to provide more wireless flexibility and self-configuration by integrating ubiquitous monitoring and management tools on TRIMEK in-house 3D CMMs for the automotive industry.

Therefore, based on the LOOP cross-layer routing strategy and traffic rules (Section 3.5), a wireless ad-hoc link was established on the factory floor resulting in highly autonomous CMM machines with high flexibility. Moreover it was established that the use of traffic rules improved the bandwidth assigned to the prioritised traffic while maintaining the quality of the video streams at the desired level. It has also been demonstrated that dynamic queue management, based on adaptive priority handling, is a key factor when trying to offer a specific quality to the provided services. Figure 16 shows the remote scan before and after LOOP technology.

5. Conclusions

Even though converged NGNs are still in their early stages, the impacts of NGN are expected to be significant to the ICT market on two levels: firstly NGN will provide the vehicle for enhancing access to communication services, and more innovative and personalised services and applications; and secondly NGN would be a basis for the UNS (Ubiquitous Network Society), where easy-to-use networks are connected at anytime, anywhere, with anything and for anyone. LOOP is one piece in the jigsaw, however more investment is required to help this vision to become a reality and to address new emerging challenges that include energy-efficient and secure communications.

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