Preface

With the recent technological developments towards making use of the ever increasing Information and Communication Technologies (ICT) it is not surprising to see a unified move towards removing this technological bottleneck from the forthcoming systems. To this effect, a brief search of one of the most popular research paper databases, IEEE Xplore, carried out on 7th December 2011, revealed 9,561 results for the term ‘Cross Layer’ being mentioned in the search and 2,074 results for the papers with the name used in the title, where over a quarter of them were published in this decade, indicating the amount of pressure on the energy and other scarce recourses of the new systems, such as smart sensors. This also indicates the need to move away from the traditional layering bottlenecks embedded in the infrastructure of our systems.

Considering that layering breaks up the holistic nature of any atomic action and its context apart from its valuable strategies, which derive their ability to manipulate their untouched properties, like any technological side effect, started to reveal some facts within the present decade. The traditional layered models of networks, while valuable conceptually and pedagogically, were never a realistic implementation of strategies, which is more obvious in autonomous systems.

Following the advent of the Open Systems Interconnected (OSI) and its further deployment for the Internet, stimulating the Internet as the main thrust for the communication infrastructure started some 30 years ago for an era where all ICT services use packets built upon layers and protocols to carry information and manipulate applications. Although these layers provide the timely desired precision and required reliability for effective services of the last five decades they all add significant overheads and associated processing-time and bandwidth overheads due to excessive moves of the packets up and down the layers for interactive processes required by the protocols making many new applications highly inefficient. This problem can become critically important and often represent a bottleneck for many multi-user applications using the wireless as their transmission media. The highly variable condition of the channel caused by distributed interference, multipath and continuously changing noise conditions can make most viable services undesirable. Therefore, due to the rapid rise of demand for wireless broadband and a ubiquitous access paradigm for future service developments the layering deficiency is important and should be resolved urgently. The Cross Layer Algorithms (CLA) in general provide new innovative ways to find suitable scheduling mechanisms for achieving optimized objectives such as minimized or bounded transmission power, delay and packet loss and maximized worst case throughput, fairness, and resource utilization.

Fundamentally, wireless comes with many potential and unique features over its wired counterparts in either forms of economical investment or ease of use paving new avenues providing a whole new range of services under a new wireless application paradigm in less than a quarter of a century under new flagships such as ubiquitous access applications and the Wireless Sensor Networks (WSN). There are, however, many serious problems hindering proper uses of this technology to deliver proper applications. With this effect and many other signs of true industrial impact from emerging wireless technological developments in various sectors of the economy, we can consider three main areas of concern: (a) extremely high consumption of processing power; (b) lack of visibility or knowledge of other layers' parameters and conditions; and (c) lack of control or flexibility to adaptively accommodate further intelligence in the communication networks.

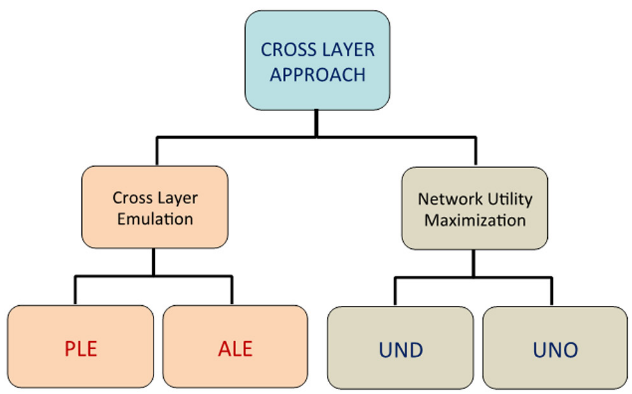
In order to explain further details here we can look further into some details. A wireless channel is inherently a shared medium. In the past century, sharing has helped the telecommunications industry to grow extensively. However, efficiency of this valuable resource heavily depends on the physical-layer's statistical structure and the nature of the users' activity where the layering complexity can be regarded as nothing but a serious bottleneck for a proper use of the channel. For example, though knowing the state of channel has a potential to improve the system's performance significantly but due to the application's overheads in a fading channel the service in a poor channel is excessively more than one estimated upon the Signal-to-Noise Ratio (SNR) in a good channel state. This problem becomes more critical if the energy consumption at the node is of vital concern where for example without a cutting across the layers may result in much higher power consumption in the device due to considerable error rates at lower transmission power and higher interferences. The followings points may exemplify the need and the benefits gained from using cross layer concepts in various aspects of wireless communications.

- Most *adaptive* systems make use of automation supported by cross-layer decisions, which is normally embedded in the device. The adaptive loading of a wireless access environment such that channel condition can be used to decide on the optimum number of users.
- The *physical* channel of wireless links is subject to serious weaknesses in the networks, usually caused by fading and to combat this is regarded as one of the key challenges in wireless networks. If not controlled properly it fades naturally creating a highly disturbing fluctuating SNR variable in the system and as a result injects heavy uncontrollable bursts of error causing heavy packet losses and sometimes a long-term outage degrading many real time services very heavily.
- *Power* for transmission and processing signals in many new wireless networks used for long term continuous monitoring and surveillance systems is a critical factor for the nodes to stay active. Power consumption can be minimized by the use of some intelligence normally available in the higher layers and the application but due to the fact that the existing layer protocols can only communicate in a strict manner with the use of intelligence and excessive waste of power for going up and down the layers we often end up in a worse condition.
- *Scheduling* is a well-established and widely used method in network design. An intelligent scheduling method that can work better than a basic round robin requires an effective use of certain network information usually gathered from various resources and network parameters counted critical to the objectives of the design.

Although cross-layer is not fundamentally intended by choice to violate strict network layering infrastructure of the existing standards, many experts believe that it may happen one day so that we will have a more flexible stack of layering and protocols standards that gives more freedom to embed intelligent layer agents enabling the systems to accommodate better and smoother systems, networks, and applications. Let us classify the cross-layering approach into two main groups upon their adoption process. One approach is *emulation* of the existing standards for a better network design as incremental improvement, where new designs merely simplify each individual system internally. We call this group Cross-Layer Emulation (CLE) which can be divided into two subgroups of Passive Layer Emulation (PLE) where the cross-layer simplifies the system for a limited number of protocols and interfaces, and Active Layer Emulation (ALE) for those extending the use of the layers' capability with extra information made available to other layers without violating the infrastructure.

The *second* group's approach makes better use of intelligence throughout the network using layer decomposition where the network is optimized for the application design rather than conforming to the standards. As these approaches consider clear objectives and are normally adopted to solve serious layering problems within unstructured ad hoc networks, we can call them the Network Utility Maximization (NUM) group. The NUM can also be divided into two subgroups of Unstructured Network Design (UND) for those with a tendency to stay compatible with the OSI as long as none of the fundamental objectives are jeopardized with Unstructured Network Optimization (UNO) for those heading towards total freedom from the traditional infrastructure (see Figure 1).

Figure 1. Cross-layer classification



Cross-layer adaptive resource allocation techniques are found to be powerful techniques for achieving high throughput and high reliability over wireless fading channels. Recently, it has been revealed in the literature that cross-layer adaptation and optimization techniques can improve the overall system level Quality of Service (QoS) performance significantly over separate single layer adaptation and optimization techniques. **Chapter 1** discusses the novel cross-layer techniques that jointly consider the physical layer channel gain as well as the upper layer buffer occupancy and traffic information in order to find transmission rate and power policies that jointly optimize transmission power, buffer delay and packet overflow for an application specific bit error rate. A conceptual study of the cross-layer adaptation and optimization techniques, which fuels necessary motivation and direction on how to implement them in different wireless standards and devices, is provided. The associated system modeling, problem formulation and solution techniques are discussed and the benefits of cross-layer adaptation and optimization techniques as compared to single-layer counterpart with numerical results are demonstrated.

Wireless communications are a fast growing part of the telecommunication market. While new types of traffic and challenges related to the wireless medium are appearing, the methodologies for designing system architectures substantially remain the same. Under the increasing pressure of market, users, and physical medium issues, designers are in need of new approaches. Cross Layer then becomes a handy solution for coping with such problems. In fact, it allows both tighter optimization of the existing functionalities, and the introduction of new ones that do not fit within the traditional protocol stack design methodology. However, Cross Layer also carries a risk due to possibly unexpected and undesired effects. **Chapter 2** provides architecture designers with a set of guidelines synthesized from an analysis of the state of art, but enriched with the perspective of the development of the future generations of communication systems such as Cognitive Radio.

Quality of service has been an open issue from the beginning, due to the Internet paradigm of delivering the datagrams as simply as possible, on a hop-by-hop basis. As an answer to the inefficiency of the legacy solutions, rethinking of Internet principles brought among other ideas the self-management. Based on a clean-slate approach applied within the FP7-4WARD project, **Chapter 3** proposes a preliminary design and implementation of a key management capability of the near Future Internet, i.e. Cross-Layer QoS. Its applications are focused on congestion control, activation of network coding and QoS-aware routing based on a modified Dijkstra's algorithm.

Improvement of wireless and sensing technology enabled us to design a new network technology called Wireless Sensor Network (WSN). However, applications are greatly limited due to the resource constraint nature of wireless sensor nodes and the lack of flexibility in protocol design, until almost all the WSN protocols are developed for different layers independently based on traditional OSI layered architecture. Nowadays, researchers are envisioned to optimize resource utilization just breaking the barrier of layer abstraction. **Chapter 4** presents basic concepts of layered architecture design and its pros and cons for Wireless Sensor Network (WSN) applications followed by a survey of different applications of Cross-Layer Design (CLD) in WSN. All the different techniques used for CLD are also discussed in detail in this chapter. Then some guidelines are provided for stable and efficient cross-layer design. Finally, some open issues are indicated to show the future direction of research in cross-layer protocol design for WSN. The chapter is concluded with the hope that the CLD will have a widespread use in next generation WSN communication.

Body Area Sensor Networks (BASN) with miniature sensors providing wireless communications capabilities have become a promising tool for monitoring and logging vital parameters of patients suffering from chronic diseases such as diabetes, asthma and heart diseases. Particularly, with the technical development in BASN, a low-cost, high quality, convenient Electrocardiographic (ECG) diagnosis system becomes a future major tool for healthcare systems. However, numerous important research issues remain to be addressed in BASN for ECG transmissions. Among these, communication energy efficiency and security are the most important issues. **Chapter 5** introduces a survey of and analyzes effective cross-layer strategies for wireless ECG transmissions in BASN. The key idea of these cross-layer communication techniques is to take advantage of both source data properties and communication strategies for the optimization of the system energy efficiency while providing secure wireless ECG transmissions. The goal of improving communication energy efficiency is achieved by matching the source coding of ECG signals with the channel coding strategy. Thanks to the dependency property of the compressed ECG data, a selective encryption algorithm needs only to be applied on a very small portion of the transmitted data. At the same time, it provides a level of security equivalent to traditional full-scale encryption using block or stream ciphers without the burden of the associated energy and computational expense. In our example of an authentication scheme, sensors for the same body can authenticate each other by common traits such as inter-pulse intervals. Authors have analyzed the proposed cross-layer technique for ECG transmissions and validated the achieved energy efficiency improvements by both simulation and experimental results.

Cross-Layer Design is useful for wireless communication to improve the performance and efficiency. On the other hand, Cross-Layer Design is also helpful in enhancing network security. With the help of cross-layer information and interactions, the security overhead can be reduced and the security efficiency can be improved. **Chapter 6** reviews the existing literature and provides a classification that based on their methods and applications. According to the survey, these cross-layer security enhancements could be classified into four categories: 1) security protocol; 2) security policy; 3) key management; 4) intrusion detection.

The design of the mobility management is the key issue in the next-generation mobile networks. It is important to provide seamless service switching for a Mobile Station (MS) or a Mobile Node (MN) with the uninterrupted services during an IP-based session between different access networks, where IP convergence has led to the co-existence of several IP-based wireless access technologies and the emergence of next generation technologies. Many research results of cross-layer design in mobility recently had been able to minimize the data loss rate and delay time during switching so that users do not experience obvious and unacceptable interruptions during the handoff. The cross-layer design is the important approach for the mobility management. **Chapter 7** introduces and reviews existing protocols and then discusses the possible interest and useful applications of cross-layer in mobility management.

Chapter 8 presents joint interference suppression and power allocation algorithms for DS-CDMA and Multiple-Input Multiple-Output (MIMO) networks with multiple hops and amplify-and-forward and Decode-and-Forward (DF) protocols. A scheme for joint allocation of power levels across the relays and linear interference suppression is proposed. Furthermore, another strategy for joint interference suppression and relay selection that maximizes the diversity available in the system, is discussed. Simulations show that the proposed cross-layer optimization algorithms obtain significant gains in capacity and performance over existing schemes.

Because of the impact of noise, interference, fading and shadowing in a wireless network, there has been a realization that the strict layering of wireline networks may be unsuitable for wireless. It is the volatility over time that demands an adaptive solution and the basis of adaptation must arise by communication of the channel conditions along with the datalink settings. Video communication is particularly vulnerable because, except when reception is decoupled from distribution as in multimedia messaging, there are some real-time displays and decoding deadlines to be met. The predictive nature of video compression also makes it susceptible to temporal error propagation. In **Chapter 9**, case studies from the authors' experiences with broadband wireless access networks and personal area wireless networks serve to illustrate how information exchange across the layers can benefit received video quality. These schemes are adaptive and serve as a small sample of a much greater population of cross-layer techniques. Given the importance of multimedia communications as an engine of growth for networked communication, 'cross-layer' should be the first consideration in designing a video application.

Most of the wireless ad hoc networks have battery-powered nodes, so a lifetime of a network depends on the power of nodes. Power conservation is one of the main issues of wireless ad hoc networks. Power conservation can be achieved in two different ways: power control algorithms and power management algorithms. Transmission power control is one of the best examples of a cross-layer design problem. The purpose of **Chapter 10** is to discuss the transmission power control problem and one possible solution by using cross layer framework through a case study. This chapter describes two cross-layer power control protocols developed at two different layers and also presents the effect of applying the combination of these protocols through a simulation study using the GloMoSim system.

Wireless Sensor Networks are a promising way to interconnect smart objects sensing and acting on the environment, enabling the Internet of Things. However, this kind of network is particularly constrained: nodes have limited energy reserve, their CPU and memory resources are limited, and the radio bandwidth is very low. After having exposed the main approaches for the routing and MAC layers, **Chapter 11** explains why they must be jointly optimized, why a metric reflecting the radio link quality is necessary and how it should integrate different criteria in layers 2 and 3. Furthermore, a new architecture based on IEEE 802.15.4 and RPL is introduced so that both protocols work in symbiosis.

Radio spectrum has become a precious resource. Most frequency bands have been allocated for exclusive use in the US. However, studies have shown that a very large portion of the radio spectrum is unused or underused for long periods of time at a given geographic location. Therefore, allowing users without a license to operate in licensed bands while causing no interference to the license holder becomes a promising way to satisfy the fast growing need for spectrum resources. Dynamic spectrum access and cognitive radio are technologies for enabling opportunistic spectrum access and enhancing the efficiency and utilization of the spectrum. A cognitive radio adapts to the environment in which it operates by sensing the spectrum and then the opportunistic exploiting of unused and/or underused frequency bands in order to achieve certain performance goals. Due to the close coupling and interaction among protocol layers, the optimal design of opportunistic spectrum access and cognitive radio networks calls for a cross-layer approach that integrates signal processing and networking with regulatory policy making. **Chapter 12** introduces basic concepts, design issues involved, and some recent development in this emerging technological field. Future research directions are also briefly examined.

One of the major limiting factors preventing wide use of wireless sensor networks in practical scenarios is power consumption. Battery-less or passive sensors promise to alleviate this issue and enable a wide variety of embedded sensor applications such as structural health and vehicular monitoring, biomedical applications, smart homes, and smart grids. Embedding these sensors in structures without the need for changing batteries, their rugged design to withstand harsh environments and coded communication with multiple access features makes this technology a desirable candidate for a variety of applications. Design and analysis of these sensors from a cross layer point of view is studied in **Chapter 13**. State of the art in fabrication and test of this new class of wireless sensor systems is also reviewed. Interactions between lower layer with passive sensors and upper layer with active sensors—a different perspective on cross layer—is exploited to achieve significant performance gains in terms of signal to noise and interference ratio, correlation peak to side-lobe ratio, operation range, and data rate.

Chapter 14 describes the different aspects related to designing a suitable monitoring architecture for Cloud Computing, aiming to support cross-layer monitoring across all layers available in the Cloud stack. For this purpose, the importance of monitoring services in Cloud scenarios is outlined, followed by a comprehensible analysis of a wide set of distributed monitoring solutions. After that, the particular requirements related to cross-layer monitoring for Cloud Computing architectures are identified and explained in this chapter. Then, diverse aspects of which may fit a monitoring architecture for fulfilling such requirements are explained. Finally, some future research directions and conclusions are highlighted.

To pervasively and diversely support a wide range of multimedia services, several traditional replication techniques have been considered for improving data accessibility in Wireless Mesh Networks (WMN). The metrics used to evaluate data accessibility performance are often related to service integrity parameters of the lower layers such as the network, medium access control, and physical layers. However, these parameters cannot directly reflect the Quality of Experience (QoE) as perceived by end users. In contrast, QoE based parameters for video streaming applications are deduced from subjective tests and involve processing at the application layer including quality of playback in terms of spatial artifacts, smooth playback, and continuous playback. In **Chapter 15**, dependencies between the different protocol layers and across the hops through WMN will be exploited to deliver video streaming with high QoE. Specifically, a cross-layer optimization approach is applied to a replication strategy for video on-demand over WMN. Additionally, a distributed implementation algorithm, namely Mod&Timer, to handle the placement of replicas for saving storage resources of the network is introduced. Simulation results are shown to demonstrate that our proposed cross-layer design outperforms many existing schemes in terms of QoE. More importantly, compared to other strategies without cross-layer interaction, the proposed cross-layer design satisfies the heterogeneous bandwidth constraint of end users.

Multiple-Input Multiple-Output (MIMO) systems, where multiple antennas are deployed at both ends of the wireless links, can significantly increase the transmission rate and reliability of wireless networks. However, due to the increasing demand for high data rates and QoS, the improved performance of MIMO systems may reach its limit. In particular, deployment of many antennas at user devices is constrained by the desired compact designs of mobile equipment. On the other hand, by exploiting the time-varying nature of wireless channels, Adaptive Modulation and Coding (AMC) at the physical layer is utilized to enhance the throughput. In addition, Automatic Repeat Request (ARQ) at the link layer may be applied to circumvent the deleterious effects of fading channels where packets detected with errors can be retransmitted. In an attempt to maximize the spectral efficiency of co-located MIMO wireless systems under prescribed QoS constraints, a cross-layer design that jointly combines Adaptive Modulation (AM) at the physical layer and ARQ at the data link layer is considered. The main purpose of **Chapter 16** is to present a general framework for performance analysis of such a cross-layer design. The presented mathematical analysis can be extended to many transmission schemes with MIMO systems including spatial multiplexing schemes (e.g., the V-BLAST system), spatial diversity schemes (e.g., orthogonal space-time block codes), and opportunistic schemes (e.g., maximum transmission ratio). This chapter will therefore present some new results for the cross-layer design for packet data transmission applied to co-located MIMO with maximum ratio transmission. In this context, closed-form expressions for the average packet error rate, average achievable spectral efficiency, and outage probability are derived. Some important results in the high SNR regime are also provided, revealing insights on how system and channel parameters affect system performance. More importantly, the mathematical analysis is proved to be a powerful tool to investigate the impact of practical issues such as channel estimation error, feedback delay, antenna correlation, and rank-deficient MIMO channel matrix, on the performance of cross-layer design.

In order to provide a heterogeneous quality of service guarantees to applications, most wireless communications standards combine the error-correcting capability of the automatic repeat request protocols at the data link control layer with the adjustment ability of adaptive modulation and coding strategies at the physical layer. In **Chapter 17**, a cross-layer multidimensional discrete-time Markov chain based queuing model is developed to jointly exploit the capabilities of the automatic repeat request protocols and adaptive modulation and coding. Based on the stationary state probability distribution of this multidimensional discrete-time Markov chain, closed-form analytical expressions for performance metrics such as throughput, average packet delay and packet loss rate are derived. Furthermore, the proposed analytical framework is used to formulate multidimensional and simplified two-dimensional constrained cross-layer optimization problems aiming at maximizing the system throughput under prescribed quality of service constraints.

Designing a wireless video communication system is a challenging task due to high error rates of wireless channel, limited and dynamically varying bandwidth availability, and low energy and complexity requirements of portable multimedia devices. Scalable video coders having excellent rate-distortion performance are most suited to cope with the time varying bandwidth of wireless networks, but encoded bits are extremely sensitive to channel errors. **Chapter 18** presents a reliable video communication system exploring opportunities offered by various network layers for improved overall performance, while optimizing the resources. More specifically, cross-layer approach for Unequal Error Protection (UEP) of scalable video bit-stream is the main theme of this chapter. In UEP, the important bits are given a higher protection compared to the other bits. Conventionally, UEP is achieved by using Forward Error Correction (FEC) at the application layer. However, UEP can also be provided at the physical layer using a hierarchical modulation scheme. In this chapter, cross-layer design methodology for UEP that rely on interaction between the application layer and the physical layer to achieve reliable and high quality end-to-end performance in wireless environments is discussed. The discussion is mainly focused on wavelet-coded video, but it is applicable to other embedded bit-streams as well.

Multimedia applications are becoming the main driver for advancement in the telecommunications industry. Increased demand for anytime anywhere mobility has given rise to the development of ad hoc networks. Supporting multimedia applications over ad hoc networks is extremely challenging due to the stringent QoS requirements and the lack of infrastructure. In the recent years, cross-layer design techniques have emerged as a potential solution to address these challenges. **Chapter 19** takes a cross-layer design approach and presents the design and analysis of wireless ad hoc networks that support multimedia applications with scalable QoS. The chapter has contributed in two areas. Firstly, a novel, cross-layer, Hierarchical Clustering, Provisioning, and Routing (HCPR) scheme for ad hoc networks, is proposed, implemented and analyzed. Secondly, a novel methodology is developed for multimedia network analysis and its effectiveness is demonstrated by the analysis of the HCPR scheme and other well-known protocols. The HCPR scheme is implemented as an extension to the OPNET simulation software and is analyzed in detail for its QoS performance to deliver multimedia applications over ad hoc networks. It is compared with three well-known and widely used routing protocols, Ad Hoc On Demand Distance Vector (AODV), Optimized Link State Routing (OLSR), and Geographic Routing Protocol (GRP). Several networking scenarios have been carefully configured with variations in networks sizes, applications, codecs, and routing protocols to extensively analyze the proposed scheme. The HCPR enabled ad hoc network outperforms the well-known routing schemes, in particular for relatively large networks and high QoS network loads. These results are promising because many QoS schemes do work for small networks and low network loads but are unable to sustain performance for large networks and high QoS loads. Several directions to extend this research for future work are given.

As IEEE 802.11 wireless devices have become increasingly widespread, providing Quality of Service in the context of H.264/AVC, the video-coding standard for future multimedia networking has become an important issue in the fields of communication and networking. Cross-Layer Adaptive Video Prioritization (CAVP) is a cross-layer framework that prioritizes video frame transmission according to the application-layer information and the MAC layer transmission condition. In **Chapter 20**, a Peak Signal-to-Noise Ratio (PSNR) estimation method is proposed to sort out different priorities of H.264/AVC (Advanced Video Coding) video frames at the application layer to provide user-Centric media quality estimation. Compared to previous heuristic algorithms, a theoretic access delay estimator to monitor the wireless medium access delay at the MAC layer is investigated. In addition, an admission control is employed to serve the delay-sensitive video application and to give higher priority to those critical video frames. Video packets are dynamically classified into different 802.11e access categories according to the level of wireless medium access delay and the priority of the video frames. The myths of naïvely prioritizing video packets based on I/P/B types as well as naïvely assign packets to high priority access categories in 802.11e are resolved. Rather than creating a complex scheme that is unable to be implemented in practical scenarios, the proposed scheme is designed with practical implementability in mind. The proposed scheme is implemented with a Click kernel module and the MadWifi WLAN driver. The performance of the proposed CAVP design is evaluated by both NS-2 simulation and real test-bed experiments, and results show that it enhances receiving video quality in error-prone wireless networking environments.

New and diverse applications for Wireless Sensor Networks (WSN) have also led to new challenges. Cross-layer approaches have proven to be the most efficient optimization techniques for these problems, since they are able to take the behavior of the protocols at each layer into consideration to overcome the constraints for WSN. Thus, **Chapter 21** focuses on identifying the core problems of WSN and collects available cross layer solutions for them that have been proposed so far. The literatures on cross-layer protocols, protocol improvements, and design methodologies for WSN are reviewed and taxonomy is proposed in order to provide insights on the identification of cross layer design in WSN. The open issues are discussed in detail for future research and precautionary guidelines for cross layer design to WSN is indicated.

In general, we are very proud to be able to receive so many quality proposals from the experts in the field to enable us to compile such a valuable piece of technological advancement for such a challenging part of today's pressing technological development.

29 February 2012

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