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Impedance Matching of Wirless Networks for Qos Based on Cross Layer Architecture.

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ABSTRACT: *As the mobile and IPTV world collides with wireless LANs and Internet-based packet data, new networking approaches will support the integration of voice and data on the composite infrastructure of cellular base stations and Ethernet based wireless access points. Providing efficient quality of service like audio, video and voice over IP besides the traditional data service. Various solutions have been proposed to provide soft QoS over Multihop wireless networks from different layers in the network protocol stack. This article highlights some of the past accomplishment and promising research avenues for an important topic in the creation of future wireless networks. In this article we address the issue of cross-layer networking, where the physical and MAC layer knowledge of the wireless medium is shared with higher layers, in order to provide efficient methods of allocating network resource and applications over the Internet. In essence, future networks will need to provide "Impedance matching" of the instantaneous radio channel conditions and capacity needs with the traffic and congestion conditions found over the packet-based world of the Internet. Furthermore, such matching will need to be co-ordinated with a wide range of particular applications and user expectations, making the topic of cross-layer networking increasingly important for the evolving wireless built out.*

I. INTRODUCTION

Each impedance matching network maximizes the system performance such as uniform power efficiency and reading range at specific distance between a transmitting and a receiving antenna. By controlling the distance-based matching networks, the power efficiency of the proposed antenna improves by up to 89% compared to the conventional antenna system with the ¯xed matching (FM) condition for distances, and the reliable reading range according to the impedance matching conditions is also increased. The proposed technique is applicable for near field communication (NFC), radio frequency identification (RFID), or wireless power transfer (WPT) devices. With the development of mobile devices such as smart phones, wireless pads, and laptops, data and voice communications become more prevalent. Furthermore, the efficiency of RF systems is vital to wireless communications

By reducing the mismatch in the RF front end systems through properly used impedance matching circuits, the transfer power efficiency or reading range is improved so that high quality communication can be achieved. Since the impedances of the reactive components in the matching circuits are frequency dependent, the impedance can only be perfectly matched at a single operating frequency or a limited band of frequencies. Therefore, tunable impedance matching networks can provide an advantage over fixed impedance matching networks by controlling lumped elements that can be optimally tuned for desired frequencies to overcome any potential impedance variations.

Over the last decade, wireless communication has evolved from the synonym of cellular phone service to an integrated audio/video/data service. Such evolution is driven by not only new hardware/software development but also the increasing dependence of human's daily life on wireless communication. For example, people expect to use smart phones for all personal communication needs, to maintain ubiquitous connections to corporate/enterprise networks at work, or to establish a wireless entertainment network at home. To satisfy these diverse demands for wireless communication, the next-generation wireless network has to provide users/applications certain Quality-of-Service (QoS).

Cross-layer Protocols for Wireless Sensor Networks

The experience gained through both scientific studies and experimental work in WSNs revealed important interactions between different layers of the network stack. These interactions are especially important for the design of communication protocols for WSNs.
As an example, the effect of wireless channel on a simple communication protocol such as flooding is investigated through testbed experiments. Accordingly, the broadcast and asymmetric nature of the

wireless channel results in a different performance than that predicted through unit disk graph mod- els (UDG). Similarly, in [38], the experimental studies reveal that the perfect- reception-within-range models can be misleading in performance evaluations due to the existence of transitional region in low power links. Moreover, in [26], guidelines for physical-layer-driven protocol and algorithm design are investigated. These existing studies strongly advocate that communication protocols for WSN need to be re-designed considering the wireless channel properties. Similarly, as pointed out in [31], the interdependency between local contention and end-to-end congestion is important to be considered in protocol design. The interdependency between these and other network layers call for adaptive cross-layer mechanisms for efficient data delivery in WSNs.

In addition to the wireless channel impact and cross-layer interactions, spatio- temporal correlation is another significant characteristic of sensor networks. Dense deployment of sensor nodes results in the sensor observations being highly correlated in the space domain. Similarly, the nature of the energy-radiating physical phenomenon yields temporal correlation between each consecutive observation of a sensor node. Exploiting the spatial and temporal correlation further improves energy efficiency of communication in WSNs .

Next, we overview representative communication protocols that are relevant to the cross-layering philosophy. Moreover, we overview a single module solution for efficient communication in WSNs.

1.1 Existing Work

Cross-layer approach has so far been used in two main context in WSNs. In many papers, the cross-layer interaction is considered, where the traditional layered structure is preserved, while each layer is informed about the conditions of other layers. However, the mechanisms of each layer still stay intact. On the other hand, there is still much to be gained by rethinking the mechanisms of network layers in a unified way so as to provide a single communication module for efficient communication in WSNs. In this section, we also focus on the cross-layer module design, where functionalities of multiple traditional layers are melted into a functional module.

In the following, the literature of WSN protocols with cross-layer principles are surveyed. We classify these studies in terms of interactions or modularity among physical (PHY), medium access control (MAC), routing, and transport layers.

MAC + PHY: In , the energy consumption analysis for physical and MAC layers is performed for three different MAC protocols. The authors provide analysis of energy consumption and conclude that single-hop communication can be more efficient if real radio models are used. Although this is an interesting result, the analysis is based on a linear network, which may not be practical in realistic scenarios.

1.2 Cross-Layer Module (XLM) for Wireless Sensor Networks

The cross-layer approach emerged recently still necessitates a unified cross-layer communication protocol for efficient and reliable event communication that con-siders transport, routing, and medium access functionalities with physical layer (wireless channel) effects for WSNs. Here, we overview a new communication paradigm, i.e., cross-layer module (XLM) for WSNs . XLM replaces the entire traditional layered protocol architecture that has been used so far in WSNs.

The basis of communication in XLM is built on the initiative concept. The initiative concept constitutes the core of XLM and implicitly incorporates the intrinsic functionalities required for successful communication in WSN. A node initiates transmission by broadcasting an RTS packet to indicate its neighbors that it has a packet to send. Upon receiving an RTS packet, each neighbor of a node decides to participate in the communication through initiative determination. Denoting the initiative as $\mathbf{I}$, it is determined as follows:

$$\mathcal{I} = \begin{cases} 1, \text{ if } \begin{cases} \xi_{RTS} \geq \xi_{Th} \\ \lambda_{relay} \leq \lambda_{relay}^{Th} \\ \beta \leq \beta^{max} \\ E_{rem} \geq E_{rem}^{min} \end{cases} \\ 0, \text{ otherwise} \end{cases}$$

where ξ_{RTS} is the received SNR value of the RTS packet, λ_{relay} is the rate of packets that are relayed by a node, β is the buffer occupancy of the node, and E_{rem} is the residual energy of the node, while the terms on the right side of the inequalities indicate the associated threshold values for these parameters, respectively. The initiative, **I**, is set to 1 if all four conditions in (1) are satisfied. The first condition ensures that reliable links be constructed for communication.

The second and third conditions are used for local congestion control in XLM. The second condition prevents congestion by limiting the traffic a node can relay. The third condition ensures that the node does not experience any buffer overflow. The last condition ensures that the remaining energy of a node E_{rem}

stays above a minimum value, E^{min}.

The cross-layer functionalities of XLM lie in these constraints that define the initiative of a node to participate in communication. Using the initiative concept, XLM performs local congestion control, hop-by-hop reliability, and distributed operation. For a successful communication, a node first initiates transmission by broadcasting an RTS packet, which serves as a link quality indicator and also helps the potential destinations to perform receiver-based contention. Then, the nodes that hear this initiation perform initiative determination according to (1). The nodes that decide to participate in the communication contend for routing of the packet by transmitting CTS packets. The waiting times for the CTS packet transmission is determined based on the advancement of a node for routing [3]. Moreover, the local congestion control component of XLM ensures energy efficient as well as reliable communication by a two-step congestion control. Analytical performance evaluation and simulation experiment results show that XLM significantly improves the communication performance and outper- forms the traditional layered protocol architectures in terms of both network performance and implementation complexity.

A cross-layer solution among MAC layer, physical phenomenon, and the ap- plication layer for WSNs is proposed in [32]. The spatial correlation in the ob- served physical phenomenon is exploited for medium access control. Based on a theoretical framework, it is shown that a sensor node can act as a representative node for several other sensor nodes. Accordingly, a distributed, spatial correlation-based collaborative medium access control (CC-MAC) protocol is proposed. Simulation results show that exploiting spatial for medium access re- sults in high performance in terms of energy, packet drop rate, and latency.

MAC + Routing: In many work, the receiver-based routing is exploited for MAC and routing cross-layer modularity. In this approach, the next hop is chosen as a result of the contention in the neighborhood. Receiver-based routing has been independently proposed in [28], [35], and [36]. In [35] and [36], the authors discuss the energy efficiency, latency, and multihop performance of the algorithm. In [37], the work in [35] and [36] is extended for a single radio node. In [28], the receiver-based routing is also analyzed based on a simple channel model and lossless links. Moreover, the latency performance of the protocol is presented based on different delay functions and collision rates. Although the authors pro- vide insightful results for the receiver-based routing, the impact of physical layer is not considered in the protocol operation. Similarly in [14], the routing decision is performed as a result of successive competitions at the medium access level. More specifically, the next hop is selected based on a weighted progress factor and the transmit power is increased successively until the most efficient node is found. Moreover, on-off schedules are used. The performance evaluations of all these propositions present the advantages of cross-layer approach at the routing and MAC layers.

A joint scheduling and routing scheme is proposed in [27] for periodic traffic in WSNs. In this scheme, the nodes form distributed on-off schedules for each flow in the network while the routes are established such that the nodes are only awake when necessary. Since the traffic is periodic, the schedules are then maintained to favor maximum efficiency. The authors also investigate the trade- off between on-off schedules and the connectivity of the network.

The usage of on-off schedules in a cross-layer routing and MAC framework is also investigated in [18]. In this work, a TDMA-based MAC scheme is de- vised, where nodes distributively select their appropriate time slots based on local topology information. The routing protocol also exploits this information for route establishment. In [18], the authors advocate the usage of cross-layer interaction through comparative simulations with a strict layered approach.

WSNs are characterized by multiple flows from closely located nodes to a single sink. However, if this fact is not considered in route establishment, potential interfering routes can be established. In [13], this effect of broadcast nature of MAC on routing is investigated. In this work, MAC interference between routes is minimized by constructing interference-aware routes. The routes are constructed using node codewords that indicate the interference level of nodes and each packet contains a route indicator for route establishment. As a result, the routes are constructed to minimize the interference among themRouting + PHY: A cross-layer optimization of network throughput for mul- tihop wireless networks is presented in [34]. The authors split the throughput optimization problem into two sub-problems, i.e., multi-hop flow routing at the network layer and power allocation at the physical layer. The throughput is tied to the per-link data flow rates, which in turn depend on the link capacities and hence, the per-node radio power level. On the other hand, the power allocation problem is tied to interference as well as the link rate. Based on this solution, a CDMA/OFDM based solution is provided such that the power control and the routing are performed in a distributed manner.

In [25], new forwarding strategies for geographic routing are proposed based on the results in [38]. The authors provide expressions for the optimal forwarding distance for networks with automatic repeat request (ARQ) and without ARQ. Moreover, two forwarding strategies for these cases are provided. The forwarding algorithms require the packet reception rate of each neighbor for determination of the next hop and construct routes accordingly. Although the new forwarding metrics illustrate the advantages of cross-layer forwarding techniques in WSNs, the analysis for the distribution of optimal hop distance is based on a linear network structure.

Transport + PHY: In [8], a cross-layer optimization solution for power con- trol and congestion control is considered. The authors provide analytical analysis of power control and congestion control, and the trade-off between layered and cross-layer approach is presented as discussed in Section 3. Based on this frame- work, a cross-layer communication protocol based on CDMA is proposed, where the transmission power and the transmission rate is controlled. However, the pro- posed solutions only apply to CDMA-based wireless multihop networks, which may not apply to WSNs that CDMA technology may not be feasible.

3-Layer Solutions: In addition to the proposed protocols that focus on pair- wise cross-layer interaction, more general cross-layer approaches among three protocol layers exist. In [22], the optimization of transmission power, transmis- sion rate, and link schedule for TDMA-based WSNs is proposed. The optimiza- tion is performed to maximize the network lifetime, instead of minimizing the total average power consumption. In [11], joint routing, MAC, and link layer optimization is proposed. The authors consider a variable-length TDMA scheme and MQAM modulation. The optimization problem considers energy consump- tion that includes both transmission energy and circuit processing energy. Based on this analysis, it is shown that single-hop communication may be optimal in some cases where the circuit energy dominates the energy consumption instead of transmission energy. Although the optimization problems presented in the paper are insightful, no communication protocol for practical implementation is proposed. Moreover, the transport layer issues such as congestion and flow control are not considered.

II. SURVIVABILITY OF WIRELESS NETWORKS

As far as survivability aspects are concerned, the purpose of our research has been mainly the extension of the swap techniques to wireless networks. In this respect, the basic assumption is that component failures are transient, and therefore the swapping to the emergency network is temporary and must be fast and as less invasive as possible. Moreover, since sooner or later each component in the network may be subject to a malfunctioning, we adopt the approach of computing the "swapping" with respect to all the possible, non-overlapping failures. In this way, on one hand we amortize the computational effort, and on the other hand we detect in advance the most vital network components (i.e., those whose removal will affect the network functionality the most), so that preventive actions to strengthen them can be accomplished. As a first step towards this direction, we focused our attention on *radio communication networks*, where mobility is not contemplated. More formally, a radio communication network is defined as a set g of radio stations located on the 3-dimensional space, d _ 1,and which can transmit and receive messages via ether. If a station ;:::;has a given *transmission range* R(s), then and all the stations within this range can receive messages directly (or, in a *single hop*) from Hence, a *range assignment* for S is station must be provided in advance with hardware and software facilities adequate to support its congestion.

As soon as a transient failure of either a non-base or a base station S happens, this will result in a disconnection of the network itself (unless is not a gateway). In we focused on failures of non-base stations, since base stations deserve a different treatment. Hence, whenever a non base station fails, all the stations in S that use s to reach their associated base, will remain isolated. How to proceed then to guarantee the network functionality? According to the swap strategy, we should make the least amount of changes on the network. This has been done by altering the global state of the minimum number of stations. More precisely we provided a time efficient solutions to the following problem: Whenever a transient failure of a non-base station happens, swap to an emergency network in which the set of stations having their range changed or congestion increased is minimum, and, under the same number of changes, with the least total power consumption.

III. MATCHING NETWORK COMPONENT SELECTION

To determine the component values of any impedance matching network at a given frequency, the source and load impedances of the matching network must be accurately defined. For the resonant wireless power system shown in Figure 1, the equivalent impedance (Z) matrix can be accurately defined by analyzing each step in the impedance path as a two-port network.

The components in each block can be defined with either ideal components, lossy components, or with extracted scattering (S) parameters from a vector network analyzer (VNA) for the most accurate analysis. For example, an inductor can be modeled as either a lossless component or as a lossy component with a series DC resistance (DCR) based on the parasitic parameters provided by the manufacturer. However, the most accurate parasitic model for an inductor can be extracted by measuring the two-port S-parameters using a VNA and importing these model parameters into a simulation tool.

Similarly for the equivalent impedance of the MCRs: the input impedance for four-element MCRs can be calculated for a given coupling coefficient using (2). However, these theoretical expressions typically neglect parasitic effects such as capacitive cross-coupling and resonator de-
tuning that can significantly reduce efficiency at the resonant frequency for a practical system. Therefore, it is most accurate to extract S-parameters from a VNA for a full range of coupling coefficients and calculate the equivalent input impedance from S_{11} as in (3). Once the impedance characteristics of each block have been defined using these techniques, the algorithms presented in this paper can be implemented to determine the necessary component values of a matching network to match the source impedance R_S to this lumped system impedance $Z_{IN,SYS}$.

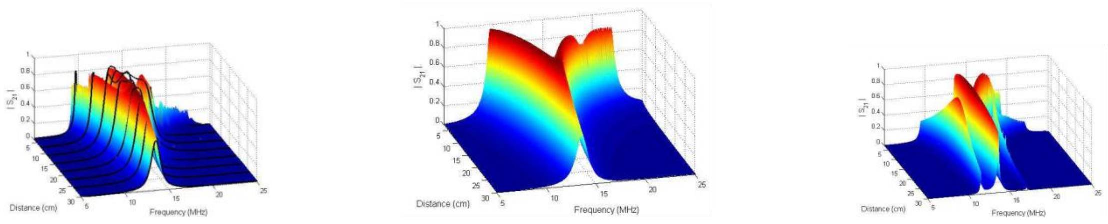
$Z_{in}=R_S-S_{11}(2)(j\omega)$

Throughout this work, a low-pass π-match impedance matching network topology will be used as in Figure 5. In contrast to an L-match topology, the π-match topology enables wideband impedance matching to load impedances that are either greater than, equal to or less than the source impedance. The low-pass π-match topology allows for a fixed inductor value to be placed in the high-current path, and variable source and load capacitor values can control the impedance matching capabilities of the matching network. This switching functionality is preferable because it is easier to implement a parallel bank of switchable capacitors than inductors in series. Additionally, the quality factor (Q_m) of the π-match network provides an extra degree of freedom to achieve wideband or narrowband impedance matching. For strongly coupled MCRs, wideband impedance matching (low Q_m) is desired, but for weak coupling, narrowband impedance matching (high Q_m) is preferable. Refer to Section 4 for an extended analysis of the π-match network implented with a set of MCRs.

IV. MODEL VALIDATIONS AND EXPERIMENTAL RESULTS

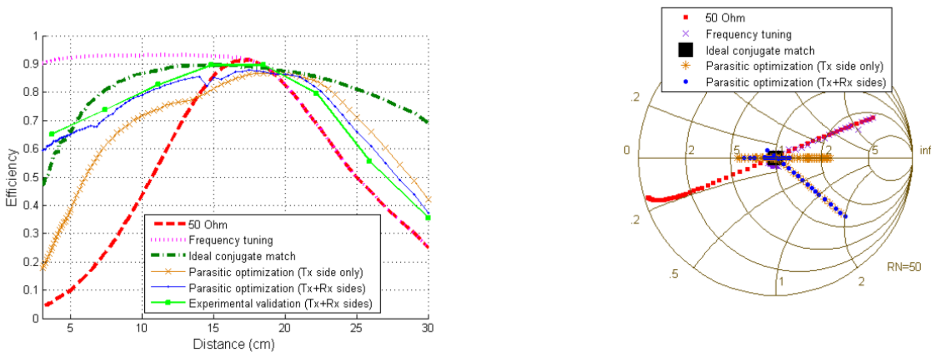
A total of 87 S-parameter datasets have been extracted using a VNA for various distances be- tween the Tx and Rx resonators shown in Figure 2(a) ranging from 0.3 cm–40 cm. These model parameters have been used to characterize the MCRs for both the ideal conjugate match and parasitic optimization algorithms presented in Section 3. A 206 nH inductor and switchable capacitors ranging from 1–1000 pF are used in the π-match AIM network. For the ideal conjugate match algorithm, both this inductor and the shunt capacitors have been modeled as ideal, lossless components. For the parasitic optimization algorithm, S-parameters provided by the manufacturer for a 206 nH air-core inductor have been used to model the inductor in the π-match network. The shunt capacitors have been modeled with a 50 mΩ ESR, a standard value for an 0603 package ceramic capacitor in the tens of MHz frequency range.

Figure 7 shows the 3D surface plots of $|S_{21,SYS}|$ versus frequency and distance between the two resonators. Figure 7(a) shows the case without an AIM network: the MCRs are terminated in 50 Ω source and load impedances. This plot demonstrates the frequency splitting effect in the over- coupled region. For a commercial application, this behavior is problematic because the efficiency at the resonant frequency of 13.56 MHz within the regulated frequency band is very low in the overcoupled regime. Figure 7(b) shows how an ideal π-match AIM network with component values selected by the simulated ideal conjugate match algorithm can confine the resonant peaks to a single ridge centered at 13.56 MHz across the entire range of separation distances. Figure 7(c) shows the effect of the simulated parasitic optimization algorithm implemented with the MCRs. For this plot, a π-match AIM network has been placed at both the Tx and Rx resonators. Although there is a significant improvement in efficiency at 13.56 MHz compared to Figure 7(a), this ridge is not as well defined as the ideal case in Figure 7(b) because parasitic components of the matching network



(a) (b) (c)

Figure 7: Surface plots of the extracted $|S_{21}|$ for the MCRs with (a) 50 Ω source and load termination impedances, (b) a π-match AIM network at the Tx side corresponding to the simulated ideal conjugate match algorithm, and (c) a π-match AIM network at both the Tx and Rx sides corresponding to the simulated parasitic optimization algorithm (surface plot) with the experimental results overlayed (black lines).



(a) (b)

Figure 8: (a) Plot of the simulated and experimental efficiency,| or $|S_{21}|^2$, and (b) a Smith chart of the simulated S_{11} are included in the simulation. This simulated surface plot is compared to experimental results shown by the black lines in Figure 7(c). The experimental dataset was extracted using a VNA with a π-match network on both sides for eight incremental distances between the resonators. The shunt capacitors are manually switched according to the recommended component values from the parasitic optimization algorithm. This result confirms that the simulated parasitic optimization algorithm accurately models the achievable experimental result.

Figure 8 directly compares the efficiency versus separation distance at a single frequency of 13.56 MHz for all of the simulated analyses and experimental result. Figure 8(a) includes single-frequency results for the MCRs terminated in 50 Ω, an ideal π-match AIM network at the Tx side based on the ideal conjugate match algorithm, a parasitic π-match AIM network at the Tx side as well as at both the Tx and Rx sides based on the parasitic optimization algorithm, and the experimental implementation of the double-sided parasitic optimization algorithm. Figure 8(a) also includes a result for wideband frequency tuning where the operating frequency is selected based on the maximum efficiency points along the low-frequency ridge in Figure 7(a). The AIM networks improve efficiency from the 50 Ω case at a single frequency in both the overcoupled and undercoupled regions, but cannot achieve efficiency as high as the frequency tuning results. Additionally, the S_{11}

Smith chart is shown in Figure 8(b) for all of these cases. S_{11} is defined on the Smith chart at 13.56 MHz for each separation distance. The ideal conjugate match algorithm provides a perfect match to the 50 Ω source impedance at the center of the smith chart. The parasitic matching network is able to confine S_{11} towards the center, but cannot provide an accurate match for all distances.

The most problematic scenario occurs for the strongest coupling between the two resonators because the bandwidth is widest for the split resonant modes at this point. An ideal matching network is able to fully recover maximum efficiency at a single frequency for this case. However, the parasitic matching network is incapable of fully recovering maximum efficiency because the load impedance presented to the matching network by the MCRs for strongest coupling is significantly less than the 50 Ω source impedance.

V. CONCLUSION

In this paper, switchable distance-based impedance matching networks for a tunable high frequency system is presented, which improve system performance by switching the predetermined impedance matching networks in the operating range, regardless of automatic control algorithms and complicated matching networks. Easy tunability is achieved simply by checking the received signal level of the three channel impedance matching networks. we have revised some of the most relevant aspects concerning the QoS in wireless networks, that is survivability, data access and layout design, by providing both the state-of-the-art and the research issues we are currently pursuing.

A cross-layer design methodology for energy-constrained wireless sensor networks is an appealing approach as long as cross-layer interactions are thoroughly studied and controlled. As pointed out in this paper, in fact, no cross-layer dependency should be left unintended, since this may lead to poor performance of the entire system.

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