

## Total Platform Cyber Protection

Multifrequency media access control has been well understood in general wireless ad hoc networks, while in wireless sensor networks, researchers still focus on single frequency solutions. In wireless sensor networks, each device is typically equipped with a single radio transceiver and applications adopt much smaller packet sizes compared to those in general wireless ad hoc networks. Hence, the multifrequency MAC protocols proposed for general wireless ad hoc networks are not suitable for wireless sensor network applications, which we further demonstrate through our simulation experiments. In this article, we propose MMSN, which takes advantage of multifrequency availability while, at the same time, takes into consideration the restrictions of wireless sensor networks. Through extensive experiments, MMSN exhibits the prominent ability to utilize parallel transmissions among neighboring nodes. When multiple physical frequencies are available, it also achieves increased energy efficiency, demonstrating the ability to work against radio interference and the tolerance to a wide range of measured time synchronization errors.

CCS Concepts: • **Security and privacy** → *Hardware attacks and countermeasures; Embedded systems security; Operating systems security; Software and application security;*

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## 1. INTRODUCTION

Traditional security defenses for the computing environment have focused on securing the *border* of the network, as this is the entry place for most attackers. However, even with sophisticated border technologies in place, there are constant attacks and data breaches against our networks. The goal of this work is to survey the state of security for the entire computing platform, in order to identify specific areas that are underserved by the research community and that require additional research and investment.

Modern computing infrastructure serves a wide array of needs, with diverse technologies and implementations: embedded systems, cloud computing, sensor networks, desktops, mobile devices, and industrial control systems. Rather than consider each of these computing platforms independently, in this work we abstracted the computing platform into several layers, each of which are applicable to every computing infrastructure. In particular, we analyzed the security research performed at the following layers of the computing platform: hardware, firmware, bus, hypervisor, operating system, application, and network layers (Figure 1).

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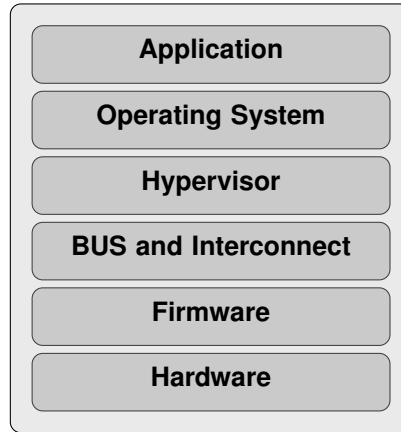


Fig. 1. Computing Platform Layers

The goal of this work is to focus research effort on *securing the entire computing platform*. An attack must effectively target a specific vulnerability in a specific layer of the computing stack, and an attacker uses that vulnerability to establish persistence on the machine, potentially attacking the underlying computing layers of the same machine or leveraging their place in the network to attack other machines. Therefore, if we wish to increase the security of our computing systems, and reduce the number and scope of security breaches, it is essential that we encourage focus on novel ideas, algorithms, and techniques to secure every level of the computing stack.

In this report, we will first discuss the computing stack, and, for every layer, we will describe the layer, identify primary threats against the layer, and summarize the research on attempts to secure that layer, and finally we will determine areas that require further research investment to ensure the security of the layer.

## 2. MMSN PROTOCOL

### 2.1. Frequency Assignment

We propose a suboptimal distribution to be used by each node, which is easy to compute and does not depend on the number of competing nodes. A natural candidate is an increasing geometric sequence, in which

$$P(t) = \frac{b^{\frac{t+1}{T+1}} - b^{\frac{t}{T+1}}}{b - 1}, \quad (1)$$

where  $t = 0, \dots, T$ , and  $b$  is a number greater than 1.

In our algorithm, we use the suboptimal approach for simplicity and generality. We need to make the distribution of the selected back-off time slice at each node conform to what is shown in Equation (1). It is implemented as follows: First, a random variable  $\alpha$  with a uniform distribution within the interval  $(0, 1)$  is generated on each node, then time slice  $i$  is selected according to the following equation:

$$i = \lfloor (T + 1) \log_b [\alpha(b - 1) + 1] \rfloor.$$

It can be easily proven that the distribution of  $i$  conforms to Equation (1).

**ALGORITHM 1:** Frequency Number Computation**Input:** Node  $\alpha$ 's ID ( $ID_\alpha$ ), and node  $\alpha$ 's neighbors' IDs within two communication hops.**Output:** The frequency number ( $FreNum_\alpha$ ) node  $\alpha$  gets assigned. $index = 0$ ;  $FreNum_\alpha = -1$ ;**repeat**     $Rnd_\alpha = \text{Random}(ID_\alpha, index)$ ;     $Found = TRUE$ ;    **for** each node  $\beta$  in  $\alpha$ 's two communication hops **do**         $Rnd_\beta = \text{Random}(ID_\beta, index)$ ;        **if** ( $Rnd_\alpha < Rnd_\beta$ ) or ( $Rnd_\alpha == Rnd_\beta$  and  $ID_\alpha < ID_\beta$ );            **then**                 $Found = FALSE$ ; **break**;        **end**    **end**    **if**  $Found$  **then**         $FreNum_\alpha = index$ ;    **else**         $index++$ ;    **end****until**  $FreNum_\alpha > -1$ ;

So protocols [Bahl 2002, Culler 2001, Zhou 2006, Adya 2001, Culler 2001; Tzamaloukas-01; Akyildiz-01] that use RTS/CTS controls<sup>1</sup> for frequency negotiation and reservation are not suitable for WSN applications, even though they exhibit good performance in general wireless ad hoc networks.

*2.1.1. Exclusive Frequency Assignment.* In exclusive frequency assignment, nodes first exchange their IDs among two communication hops so that each node knows its two-hop neighbors' IDs. In the second broadcast, each node beacons all neighbors' IDs it has collected during the first broadcast period.

*Eavesdropping.* Even though the even selection scheme leads to even sharing of available frequencies among any two-hop neighborhood, it involves a number of two-hop broadcasts. To reduce the communication cost, we propose a lightweight eavesdropping scheme.

**2.2. Basic Notations**

As Algorithm 1 states, for each frequency number, each node calculates a random number ( $Rnd_\alpha$ ) for itself and a random number ( $Rnd_\beta$ ) for each of its two-hop neighbors with the same pseudorandom number generator.

Bus masters are divided into two disjoint sets,  $\mathcal{M}_{RT}$  and  $\mathcal{M}_{NRT}$ .

*RT Masters.*  $\mathcal{M}_{RT} = \{\vec{m}_1, \dots, \vec{m}_n\}$  denotes the  $n$  RT masters issuing real-time constrained requests. To model the current request issued by an  $\vec{m}_i$  in  $\mathcal{M}_{RT}$ , three parameters—the recurrence time ( $r_i$ ), the service cycle ( $c_i$ ), and the relative deadline ( $d_i$ )—are used, with their relationships.

*NRT Masters.*  $\mathcal{M}_{NRT} = \{\vec{m}_{n+1}, \dots, \vec{m}_{n+m}\}$  is a set of  $m$  masters issuing nonreal-time constrained requests. In our model, each  $\vec{m}_j$  in  $\mathcal{M}_{NRT}$  needs only one parameter, the service cycle, to model the current request it issues.

<sup>1</sup>RTS/CTS controls are required to be implemented by 802.11-compliant devices. They can be used as an optional mechanism to avoid Hidden Terminal Problems in the 802.11 standard and protocols based on those similar to [Akyildiz 2001] and [Adya 2001].

Fig. 2. Code before preprocessing.

Here, a question may arise, since each node has a global ID. Why don't we just map nodes' IDs within two hops into a group of frequency numbers and assign those numbers to all nodes within two hops?

### 3. SIMULATOR

If the model checker requests successors of a state which are not created yet, the state space uses the simulator to create the successors on-the-fly. To create successor states the simulator conducts the following steps.

- (1) Load state into microcontroller model.
- (2) Determine assignments needed for resolving nondeterminism.
- (3) For each assignment.
  - (a) either call interrupt handler or simulate effect of next instruction, or
  - (b) evaluate truth values of atomic propositions.
- (4) Return resulting states.

Figure 2 shows a typical microcontroller C program that controls an automotive power window lift. The program is one of the programs used in the case study described in Section 4. At first sight, the programs looks like an ANSI C program. It contains function calls, assignments, if clauses, and while loops.

#### 3.1. Problem Formulation

The objective of variable coalescence-based offset assignment is to find both the coalescence scheme and the MWPC on the coalesced graph. We start with a few definitions and lemmas for variable coalescence.

*Definition 3.1 (Coalesced Node (C-Node)).* A C-node is a set of live ranges (webs) in the AG or IG that are coalesced. Nodes within the same C-node cannot interfere with each other on the IG. Before any coalescing is done, each live range is a C-node by itself.

*Definition 3.2 (C-AG (Coalesced Access Graph)).* The C-AG is the access graph after node coalescence, which is composed of all C-nodes and C-edges.

LEMMA 3.3. *The C-MWPC problem is NP-complete.*

PROOF. C-MWPC can be easily reduced to the MWPC problem assuming a coalescence graph without any edge or a fully connected interference graph. Therefore, each C-node is an uncoalesced live range after value separation and C-PC is equivalent to PC. A fully connected interference graph is made possible when all live ranges interfere with each other. Thus, the C-MWPC problem is NP-complete.  $\square$

LEMMA 3.4 (LEMMA SUBHEAD). *The solution to the C-MWPC problem is no worse than the solution to the MWPC.*

PROOF. Simply, any solution to the MWPC is also a solution to the C-MWPC. But some solutions to C-MWPC may not apply to the MWPC (if any coalescing were made).  $\square$

### 4. PERFORMANCE EVALUATION

During all the experiments, the Geographic Forwarding (GF) [Akyildiz 2001] routing protocol is used. GF exploits geographic information of nodes and conducts local data-forwarding to achieve end-to-end routing. Our simulation is configured according to

Table I. Simulation Configuration

TERRAIN <sup>a</sup>	(200m×200m) Square
Node Number	289
Node Placement	Uniform
Application	Many-to-Many/Gossip CBR Streams
Payload Size	32 bytes
Routing Layer	GF
MAC Layer	CSMA/MMSN
Radio Layer	RADIO-ACCNOISE
Radio Bandwidth	250Kbps
Radio Range	20m–45m

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<sup>a</sup>This is a table footnote. This is a table footnote. This is a table footnote.

the settings in Table I. Each run lasts for 2 minutes and repeated 100 times. For each data value we present in the results, we also give its 90% confidence interval.

## 5. CONCLUSIONS

In this article, we develop the first multifrequency MAC protocol for WSN applications in which each device adopts a single radio transceiver. The different MAC design requirements for WSNs and general wireless ad-hoc networks are compared, and a complete WSN multifrequency MAC design (MMSN) is put forth. During the MMSN design, we analyze and evaluate different choices for frequency assignments and also discuss the nonuniform back-off algorithms for the slotted media access design.

## 6. TYPICAL REFERENCES IN NEW ACM REFERENCE FORMAT

A paginated journal article [Abril and Plant 2007], an enumerated journal article [Cohen et al. 2007], a reference to an entire issue [Cohen 1996], a monograph (whole book) [Kosiur 2001], a monograph/whole book in a series (see 2a in spec. document) [Harel 1979], a divisible-book such as an anthology or compilation [Editor 2007] followed by the same example, however we only output the series if the volume number is given [Editor 2008] (so Editor00a's series should NOT be present since it has no vol. no.), a chapter in a divisible book [Spector 1990], a chapter in a divisible book in a series [Douglass et al. 1998], a multi-volume work as book [Knuth 1997], an article in a proceedings (of a conference, symposium, workshop for example) (paginated proceedings article) [Ander 1979], a proceedings article with all possible elements [Smith 2010], an example of an enumerated proceedings article [Gundy et al. 2007], an informally published work [Harel 1978], a doctoral dissertation [Clarkson 1985], a master's thesis: [Anisi 2003], an online document / world wide web resource [Thornburg 2001], [Ablamowicz and Fauser 2007], [Poker-Edge.Com 2006], a video game (Case 1) [Obama 2008] and (Case 2) [Novak 2003] and [Lee 2005] and (Case 3) a patent [Scientist 2009], work accepted for publication [Rous 2008], 'YYYYb'-test for prolific author [Saeedi et al. 2010a] and [Saeedi et al. 2010b]. Other cites might contain 'duplicate' DOI and URLs (some SIAM articles) [Kirschmer and Voight 2010]. Boris / Barbara Beeton: multi-volume works as books [Hörmander 1985b] and [Hörmander 1985a].

## APPENDIX

In this appendix, we measure the channel switching time of Micaz [CROSSBOW] sensor devices. In our experiments, one mote alternately switches between Channels 11 and 12. Every time after the node switches to a channel, it sends out a packet imme-

diately and then changes to a new channel as soon as the transmission is finished. We measure the number of packets the test mote can send in 10 seconds, denoted as  $N_1$ . In contrast, we also measure the same value of the test mote without switching channels, denoted as  $N_2$ . We calculate the channel-switching time  $s$  as

$$s = \frac{10}{N_1} - \frac{10}{N_2}.$$

By repeating the experiments 100 times, we get the average channel-switching time of Micaz motes: 24.3 $\mu$ s.

## ELECTRONIC APPENDIX

The electronic appendix for this article can be accessed in the ACM Digital Library.

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