Single-view TSDF Mesh Noise Reduction under Virtual Light Using Differentiable Rendering

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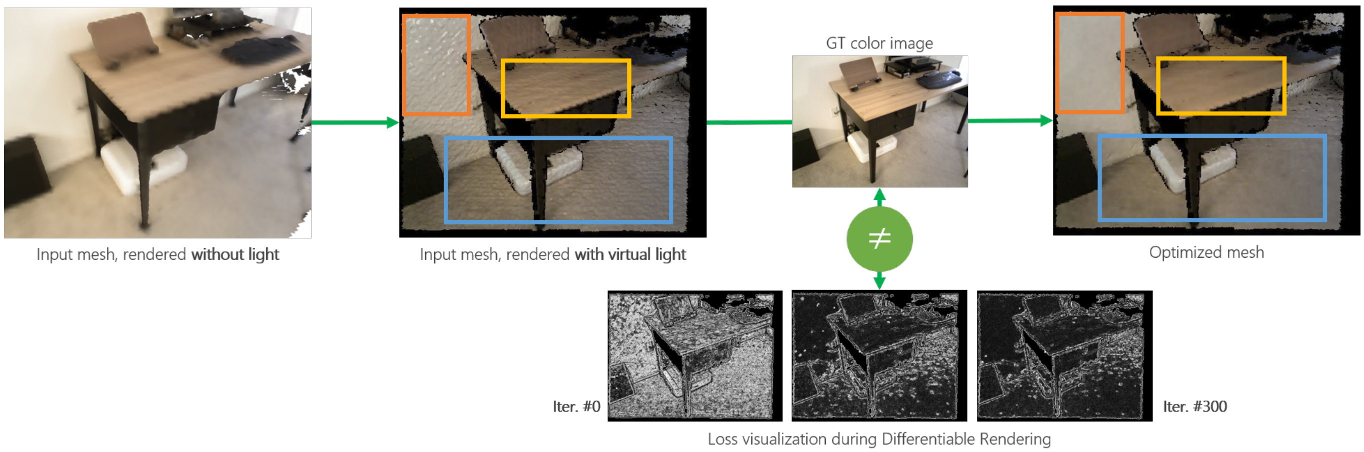

Fig. 1. Overview of our method. (From top left) We saturate noisy vertices by rendering input TSDF mesh with virtually placed light source. We extract common-shared geometric clue between rendered input mesh and target color image. Differentiable renderer iteratively minimizes loss, which is the difference between clues from rendered input mesh and target Ground Truth color image. Orange, Yellow, and Blue inset shows difference between input mesh and optimized mesh. Our method successfully reduces noise in mesh vertices. Furthermore, our provided video shows input mesh that is being optimized (right-side of the video) as iteration continues, as well as the visualization of loss (left-side of the video) that is being minimized: https://drive.google.com/file/d/10F_I89m5O-RWOIxocYoxG2QOkJc7YWlF/view?usp=sharing

Thanks to consistent evolution of SLAM (Simultaneous Localization and Mapping) and its related technologies, we can reconstruct geometric properties of where we are currently observing in real-time. Due to the limitation of current depth sensing hardware, however, we are generally able to obtain geometric features corrupted by noise. Color image is perceived as geometrically noise-free in terms of human vision-perception system, but to our best knowledge, encoding the information from Ground Truth for differentiable rendering under single view constraint is not discussed yet. In this report, we propose a bridge between the geometric information generated from color image and rendered mesh, so that differentiable renderer can optimize input i.e., noisy vertex position without any depth supervision. The key insight is that we can highlight noisy vertices by rendering mesh with virtually placed light sources. We compare our result with one of the state-of-the-art differentiable rendering method[1], and show our method outperforms previous method which requires prior depth information (silhouette image).

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

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Additional Key Words and Phrases: Wireless sensor networks, media access control, multi-channel, radio interference, time synchronization

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1 INTRODUCTION

As a new technology, Wireless Sensor Networks (WSNs) has a wide range of applications [Akyildiz et al. 2002; Bahl et al. 2004; Culler et al. 2004], including environment monitoring, smart buildings, medical care, industrial and military applications. Among them, a recent trend is to develop commercial sensor networks that require pervasive sensing of both environment and human beings, for example, assisted living [Akyildiz et al. 2007; CROSSBOW 2008; Harvard CodeBlue 2008] and smart homes [Adya et al. 2004; CROSSBOW 2008; Harvard CodeBlue 2008].

> "For these applications, sensor devices are incorporated into human cloths [Adya et al. 2004; Bahl et al. 2004; Natarajan et al. 2007; Zhou et al. 2008] for monitoring health related information like EKG readings, fall detection, and voice recognition".

While collecting all these multimedia information [Akyildiz et al. 2007] requires a high network throughput, off-the-shelf sensor devices only provide very limited bandwidth in a single channel: 19.2 Kbps in MICA2 [Bahl et al. 2004] and 250 Kbps in MICAz.

In this article, we propose MMSN, abbreviation for Multifrequency Media access control for wireless Sensor Networks. The main contributions of this work can be summarized as follows.

- To the best of our knowledge, the MMSN protocol is the first multifrequency MAC protocol especially designed for WSNs, in which each device is equipped with a single radio transceiver and the MAC layer packet size is very small.
- Instead of using pairwise RTS/CTS frequency negotiation [Adya et al. 2004; Culler et al. 2004; Tzamaloukas and Garcia-Luna-Aceves 2000; Zhou et al. 2008], we propose lightweight frequency assignments, which are good choices for many deployed comparatively static WSNs.
- We develop new toggle transmission and snooping techniques to enable a single radio transceiver in a sensor device to achieve scalable performance, avoiding the nonscalable “one control channel + multiple data channels” design [Natarajan et al. 2007].

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

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

where $t = 0, \ldots, T$, 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 α 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).

So protocols [Adya et al. 2004; Akyildiz et al. 2002; Bahl et al. 2004; Culler et al. 2004; Tzamaloukas and Garcia-Luna-Aceves 2000; Zhou et al. 2008] that use RTS/CTS controls[1] 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.

[1]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 et al. 2002] and [Adya et al. 2004].

ALGORITHM 1: Frequency Number Computation

Input: Node α's ID (ID_α), and node α's neighbors' IDs within two communication hops.
Output: The frequency number ($FreNum_\alpha$) node α gets assigned.
$index$ = 0; $FreNum_\alpha$ = -1;
repeat
  Rnd_α = Random(ID_α, $index$);
  $Found$ = $TRUE$;
  for *each node β in α's two communication hops* **do**
    Rnd_β = Random(ID_β, $index$);
    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 $FreNum_\alpha > -1$;

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_α) for itself and a random number (Rnd_β) 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 $\mathcal{M}_{RT} = \{\vec{m}_1, \ldots, \vec{m}_n\}$ 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 $\mathcal{M}_{NRT} = \{\vec{m}_{n+1}, \ldots, \vec{m}_{n+m}\}$ 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.

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.

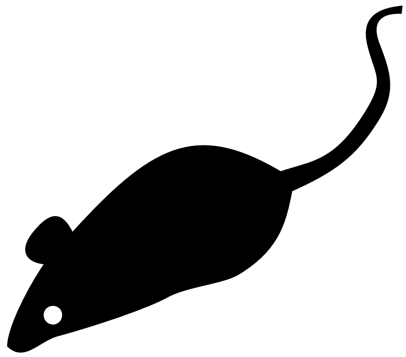

Fig. 2. Code before preprocessing.

(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 3. 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. □

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

Table 1. Simulation Configuration

TERRAIN[a]	(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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[a]This is a table footnote. This is a table footnote. This is a table footnote.

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). □

4 PERFORMANCE EVALUATION

During all the experiments, the Geographic Forwarding (GF) by Akyildiz et al. [2002] 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 the settings in Table 1. 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) [Andler 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 [Ablamowicz and Fauser 2007; Poker-Edge.Com 2006; Thornburg 2001], 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].

A couple of citations with DOIs: [IEEE 2004; Kirschmer and Voight 2010].

Online citations: [Thornburg 2001; TUG 2017; Veytsman [n.d.]].

REFERENCES

Rafal Ablamowicz and Bertfried Fauser. 2007. *CLIFFORD: a Maple 11 Package for Clifford Algebra Computations, version 11.* Retrieved February 28, 2008 from http://math.tntech.edu/rafal/cliff11/index.html

Patricia S. Abril and Robert Plant. 2007. The patent holder's dilemma: Buy, sell, or troll? *Commun. ACM* 50, 1 (Jan. 2007), 36–44. https://doi.org/10.1145/1188913.1188915

A. Adya, P. Bahl, J. Padhye, A.Wolman, and L. Zhou. 2004. A multi-radio unification protocol for IEEE 802.11 wireless networks. In *Proceedings of the IEEE 1st International Conference on Broadnets Networks (BroadNets'04)*. IEEE, Los Alamitos, CA, 210–217.

I. F. Akyildiz, T. Melodia, and K. R. Chowdhury. 2007. A Survey on Wireless Multimedia Sensor Networks. *Computer Netw.* 51, 4 (2007), 921–960.

I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci. 2002. Wireless Sensor Networks: A Survey. *Comm. ACM* 38, 4 (2002), 393–422.

Sten Andler. 1979. Predicate Path expressions. In *Proceedings of the 6th. ACM SIGACT-SIGPLAN symposium on Principles of Programming Languages (POPL '79)*. ACM Press, New York, NY, 226–236. https://doi.org/10.1145/567752.567774

David A. Anisi. 2003. *Optimal Motion Control of a Ground Vehicle.* Master's thesis. Royal Institute of Technology (KTH), Stockholm, Sweden.

P. Bahl, R. Chancre, and J. Dungeon. 2004. SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks. In *Proceeding of the 10th International Conference on Mobile Computing and Networking (MobiCom'04)*. ACM, New York, NY, 112–117.

Kenneth L. Clarkson. 1985. *Algorithms for Closest-Point Problems (Computational Geometry).* Ph.D. Dissertation. Stanford University, Palo Alto, CA. UMI Order Number: AAT 8506171.

Jacques Cohen (Ed.). 1996. Special issue: Digital Libraries. *Commun. ACM* 39, 11 (Nov. 1996).

Sarah Cohen, Werner Nutt, and Yehoshua Sagic. 2007. Deciding equivalances among conjunctive aggregate queries. *J. ACM* 54, 2, Article 5 (April 2007), 50 pages. https://doi.org/10.1145/1219092.1219093

CROSSBOW 2008. XBOW Sensor Motes Specifications. http://www.xbow.com.

D. Culler, D. Estrin, and M. Srivastava. 2004. Overview of Sensor Networks. *IEEE Comput.* 37, 8 (Special Issue on Sensor Networks) (2004), 41–49.

Bruce P. Douglass, David Harel, and Mark B. Trakhtenbrot. 1998. Statecarts in use: structured analysis and object-orientation. In *Lectures on Embedded Systems*, Grzegorz Rozenberg and Frits W. Vaandrager (Eds.). Lecture Notes in Computer Science, Vol. 1494. Springer-Verlag, London, 368–394. https://doi.org/10.1007/3-540-65193-4_29

Ian Editor (Ed.). 2007. *The title of book one* (1st. ed.). The name of the series one, Vol. 9. University of Chicago Press, Chicago. https://doi.org/10.1007/3-540-09237-4

Ian Editor (Ed.). 2008. *The title of book two* (2nd. ed.). University of Chicago Press, Chicago, Chapter 100. https://doi.org/10.1007/3-540-09237-4

Matthew Van Gundy, Davide Balzarotti, and Giovanni Vigna. 2007. Catch me, if you can: Evading network signatures with web-based polymorphic worms. In *Proceedings of the first USENIX workshop on Offensive Technologies (WOOT '07)*. USENIX Association, Berkley, CA, Article 7, 9 pages.

David Harel. 1978. *LOGICS of Programs: AXIOMATICS and DESCRIPTIVE POWER.* MIT Research Lab Technical Report TR-200. Massachusetts Institute of Technology, Cambridge, MA.

David Harel. 1979. *First-Order Dynamic Logic.* Lecture Notes in Computer Science, Vol. 68. Springer-Verlag, New York, NY. https://doi.org/10.1007/3-540-09237-4

Harvard CodeBlue 2008. CodeBlue: Sensor Networks for Medical Care. http://www.eecs.harvard.edu/mdw/ proj/codeblue/.

Lars Hörmander. 1985a. *The analysis of linear partial differential operators. III.* Grundlehren der Mathematischen Wissenschaften [Fundamental Principles of Mathematical Sciences], Vol. 275. Springer-Verlag, Berlin, Germany. viii+525 pages. Pseudodifferential operators.

Lars Hörmander. 1985b. *The analysis of linear partial differential operators. IV.* Grundlehren der Mathematischen Wissenschaften [Fundamental Principles of Mathematical Sciences], Vol. 275. Springer-Verlag, Berlin, Germany. vii+352 pages. Fourier integral operators.

IEEE 2004. IEEE TCSC Executive Committee. In *Proceedings of the IEEE International Conference on Web Services (ICWS '04)*. IEEE Computer Society, Washington, DC, USA, 21–22. https://doi.org/10.1109/ICWS.2004.64

Markus Kirschmer and John Voight. 2010. Algorithmic Enumeration of Ideal Classes for Quaternion Orders. *SIAM J. Comput.* 39, 5 (Jan. 2010), 1714–1747. https://doi.org/10.1137/080734467

Donald E. Knuth. 1997. *The Art of Computer Programming, Vol. 1: Fundamental Algorithms (3rd. ed.).* Addison Wesley Longman Publishing Co., Inc.

David Kosiur. 2001. *Understanding Policy-Based Networking* (2nd. ed.). Wiley, New York, NY.

Newton Lee. 2005. Interview with Bill Kinder: January 13, 2005. Video. *Comput. Entertain.* 3, 1, Article 4 (Jan.-March 2005). https://doi.org/10.1145/1057270.1057278

A. Natarajan, M. Motani, B. de Silva, K. Yap, and K. C. Chua. 2007. Investigating Network Architectures for Body Sensor Networks. In *Network Architectures*, G. Whitcomb and P. Neece (Eds.). Keleuven Press, Dayton, OH, 322–328. arXiv:960935712 [cs]

Dave Novak. 2003. Solder man. Video. In *ACM SIGGRAPH 2003 Video Review on Animation theater Program: Part I - Vol. 145 (July 27–27, 2003)*. ACM Press, New York, NY, 4. https://doi.org/99.9999/woot07-S422

Barack Obama. 2008. A more perfect union. Video. Retrieved March 21, 2008 from http://video.google.com/videoplay?docid=6528042696351994555

Poker-Edge.Com. 2006. Stats and Analysis. Retrieved June 7, 2006 from http://www.poker-edge.com/stats.php

Bernard Rous. 2008. The Enabling of Digital Libraries. *Digital Libraries* 12, 3, Article 5 (July 2008). To appear.

Mehdi Saeedi, Morteza Saheb Zamani, and Mehdi Sedighi. 2010a. A library-based synthesis methodology for reversible logic. *Microelectron. J.* 41, 4 (April 2010), 185–194.

Mehdi Saeedi, Morteza Saheb Zamani, Mehdi Sedighi, and Zahra Sasanian. 2010b. Synthesis of Reversible Circuit Using Cycle-Based Approach. *J. Emerg. Technol. Comput. Syst.* 6, 4 (Dec. 2010).

Joseph Scientist. 2009. The fountain of youth. Patent No. 12345, Filed July 1st., 2008, Issued Aug. 9th., 2009.

Stan W. Smith. 2010. An experiment in bibliographic mark-up: Parsing metadata for XML export. In *Proceedings of the 3rd. annual workshop on Librarians and Computers (LAC '10, Vol. 3)*, Reginald N. Smythe and Alexander Noble (Eds.). Paparazzi Press, Milan Italy, 422–431. https://doi.org/99.9999/woot07-S422

Asad Z. Spector. 1990. Achieving application requirements. In *Distributed Systems* (2nd. ed.), Sape Mullender (Ed.). ACM Press, New York, NY, 19–33. https://doi.org/10.1145/90417.90738

Harry Thornburg. 2001. *Introduction to Bayesian Statistics.* Retrieved March 2, 2005 from http://ccrma.stanford.edu/~jos/bayes/bayes.html

TUG 2017. *Institutional members of the TEX Users Group.* Retrieved May 27, 2017 from http://wwtug.org/instmem.html

A. Tzamaloukas and J. J. Garcia-Luna-Aceves. 2000. *Channel-Hopping Multiple Access.* Technical Report I-CA2301. Department of Computer Science, University of California, Berkeley, CA.

Boris Veytsman. [n.d.]. *acmart—Class for typesetting publications of ACM.* Retrieved May 27, 2017 from http://www.ctan.org/pkg/acmart

G. Zhou, J. Lu, C.-Y. Wan, M. D. Yarvis, and J. A. Stankovic. 2008. *Body Sensor Networks.* MIT Press, Cambridge, MA.

A SWITCHING TIMES

In this appendix, we measure the channel switching time of Micaz [CROSSBOW 2008] sensor devices. In our experiments, one mote alternatingly switches between Channels 11 and 12. Every time after the node switches to a channel, it sends out a packet immediately 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 μs.