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# IEEE Recommended Practice for Nanoscale and Molecular Communication Framework

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New York, NY 10016-5997
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IEEE Std 1906.1™-2015

# IEEE Recommended Practice for Nanoscale and Molecular Communication Framework

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**IEEE Communications Society**

Approved 5 December 2015

**IEEE-SA Standards Board**

**Acknowledgments:** The IEEE 1906.1 Working Group would like to thank Dr. Norbert Fabricius, Karlsruhe Institute of Technology, Secretary IEC/TC 113 and Secretary CLC/SR 113, for presenting the terminology and definitions being developed within the relevant IEC working groups. This enabled us to avoid conflicting definitions and terminology.

**Abstract:** A definition, terminology, conceptual model, and standard metrics for ad hoc network communication at the nanoscale are provided. Human-engineered networking is extended by the physical properties of nanoscale communication in ways beyond that defined in existing communication standards. These include in vivo, sub-cellular medical communication, smart materials and sensing at the molecular level, and the ability to operate in environments that would be too harsh for macroscale communication mechanisms to operate. Collaboration among a highly diverse set of disciplines with differing definitions and connotations for some terms is required by nanoscale communication, thus a common terminology is necessary in order to aid inter-discipline collaboration. A common framework for thinking abstractly about nanoscale communication can aid in defining and relating research and development effort. Components of the framework are independent enough to allow them to be developed in relative isolation, yet the components are also interoperable. To illustrate the recommended practice, example mappings between specific nanoscale communication use-cases and the common framework are included. Simulation code implementing the common framework for both wireless and molecular nanoscale communication is an embodiment of the common framework demonstrating precisely how the framework is applied.

**Keywords:** communication networks, communication standards, communication systems, IEEE 1906.1, molecular communication, multi-scale network, nanobioscience, nanobiotechnology, nanobots, nanodevice, nanoelectrochemical systems, nanoelectromechanical systems, nanofluidics, nanomedicine, nanophysics, nanopositioning, nanoscale, nanoscale communication framework, nanoscale devices, nanosensors, nanostructured materials, nanotechnology, nanotube devices, nanowires, quantum mechanics, simulation, standards development



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PDF: ISBN 978-1-5044-0101-2 STD20511
Print: ISBN 978-1-5044-0102-9 STDPD20511

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## Introduction

This introduction is not part of IEEE Std 1906.1-2015, IEEE Recommended Practice for Nanoscale and Molecular Communication Framework.

Nanoscale communication is expected to offer unprecedented benefits. For progress in the development of this technology to accelerate, clear, common definitions and a conceptual framework are needed to solidify and guide research toward practical systems. A conceptual framework is used to make conceptual distinctions and organize ideas. The word *framework* is a shortened form of *conceptual framework*. A conceptual framework provides the organization and structure required to develop conceptual models of nanoscale communication. Indeed, the lack of precise definitions and a general framework for nanoscale communication has resulted in limited impact and dissipated effort. The IEEE Std 1906.1 Recommended Practice for Nanoscale and Molecular Communication Framework provides this precise, common definition of nanoscale communication and a general framework that balances definitional precision with broad applicability. This includes metrics, use-cases, and a reference model implemented in a simulation environment. This effort is expected to facilitate research and development in nanoscale communication in a coherent manner that will enable collaboration and more rapid advancement.

The reference model is implemented in the form of Network Simulator-3 (ns-3) code that implements the IEEE 1906.1 framework. The code simulates the standard in several embodiments, one simulating molecular nanoscale communication, and another simulating electromagnetic (EM) nanoscale communication. In the EM nanoscale communication embodiment, the propagation model provides path loss and molecular absorption noise experienced in human tissue because medical applications are a promising application for nanoscale communication. These phenomena can be used to evaluate 1) the signal-to-interference ratio as a function of the power transmission and the distance between sender and receiver and 2) an upper bound on the channel capacity computed. In the molecular nanoscale communication embodiment, it is assumed that molecules move into the medium following the omnidirectional Fick's law. Knowing the number of molecules released for each pulse and the diffusion coefficient (assumed constant), the model computes the molecular concentration as a function of distance and time, evaluates the propagation delay, and estimates the maximum channel capacity when a concentration based receiver is used. In both cases, it is possible to execute simulations aimed at investigating the channel capacity experienced by a nanoscale communication link established between two devices, by changing physical detail (i.e., power transmission for the EM embodiment, diffusion coefficient and number of molecules for the molecular nanoscale communication embodiment). The simulator offers scripts to execute and process simulations as well as to generate graphs (e.g., channel capacity versus distance) via MATLAB®.[a] The ns-3 IEEE 1906.1 reference code is available from http://standards.ieee.org/downloads/1906/1906.1/P1906.1/.

[a] MATLAB is a registered trademark of The MathWorks, Inc.

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## 1. Overview

This recommended practice provides a definition, common framework, and common parameters for nanoscale communication networks. There is currently no standard or recommended practice that defines precisely what a nanoscale communication network is, nor how its components should be viewed in a conceptual framework, nor precise definitions of standardized parameters and components for interoperable simulation modules. The lack of a standard in these areas has hindered research and development of this technology. The goal of this recommended practice is to provide a general framework that partitions the problem in such a way as to allow research and development to focus on specific, individual components that interoperate with one another. It also allows researchers to focus on specific components while being able to make assumptions about the environment in which those components will reside.

To date, few academic papers claiming to contribute to nanoscale communication networking attempt to precisely define nanoscale communication. The lack of a well-defined problem prevents coherent advances in the technology. In effect, each researcher is chasing a different and often unrelated goal and the lack of a common framework and definition prevents progress from taking place by building upon previous results. One reason reaching a common definition for nanoscale communication is difficult is due in part to the need for researchers from diverse fields to reach a common understanding of the topic, ranging from information theorists and physicists to biologists; a common terminology and definition are required in order to avoid miscommunication of ideas. Researchers can be separated by the same terminology, for example *communication* might mean one thing to a biologist (entities in direct contact with one another) and something different to an information theorist (transmission of information measured via information entropy). These diverse fields also often have different overarching goals; for example, information theorists focus on information entropy, biologists focus on *mechanism,* that is, understanding and manipulating systems of causally interacting phenomena and processes that produce measurable effects,