IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**Coexistence, Interoperability, and Other Terms**
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Abstract	This contribution attempts to define the terms Coexistence and Interoperability, so that we have a common understanding. This will aid in the defining of coexistence models and performance metrics in order to perform simulation studies and experiments. Other related terms are given to show the relationship among the various terms.
Purpose	To agree on the meanings of the terms: coexistence and interoperability.
Notice	
Release	

Introduction.

At the Montreal meeting a new study group was proposed to cover the areas of coexistence and interoperability. Later the area of the interoperability was removed. At the Santa Rosa in California a discussion of the definitions and inclusion of the area of interoperability occurred with a request for clarification on the issues of coexistence and interoperability. This contribution provides background information on these two items, as well as other related information.

This contribution attempts to define the terms: coexistence, interoperability, operability and discusses the relationship and differences between conformance, operability, interoperability, and performance testing.

It is intended that this contribution be discussed so that a common understanding and agreement can be reached on these terms or definitions.

Definitions

The list of definitions below has been complied from various sources considering various applications.

1a) **coexistence** – Multiple wireless devices are said to “coexist” if they can be collocated without significantly impacting the performance of any of these devices [IEEE 802.15-99/088r2].

1b) **coexistence** - The ability of one system to perform a task in a given (shared) environment where other systems may or may not be using the same set of rules.

2a) **conformance** - The ability of a system to follow a single set of rules.

2b) **conformance** (acceptance tests) – Tests made when required to demonstrate elected performance characteristics of a product or representative samples thereof. [IEEE Std. Dictionary]

3) **conformance testing** - Testing the extent to which an implementation under test (IUT) is a conforming implementation. [ISO 9646]

4) **conforming** implementation - An IUT which satisfies both static and dynamic conformance requirements consistent with the capabilities stated in the Implementation Conformance Statement (ICS) [ISO 9646]

5) **interoperate** (software) - The ability for two or more systems to exchange information and to mutually use the information that has been exchanged. [IEEE Std. Dictionary]

6) **interoperability** - The ability of two systems to perform a given task using a single set of rules.

7) **interwork** - The ability of two systems to perform a task given that each system implements a different set of rules.

8a) **interworking** (between networks) – The means thereby terminals connected to a telecommunication network may communicate with terminals of another network. [IEC 1992]

8b) **interworking** – To express interactions between networks, between end systems, or between parts thereof, with the aim of providing a functional entity capable of supporting an end-to-end communication. The interactions required to provide a functional entity rely on functions and on the means to select these functions. [ITU-T I.510]

9) **IUT** - An implementation of one or more OSI protocols in an adjacent user/provider relationship, being that part of a real open system, which is to be studied by testing. [ISO 9646]

10) **operability** – The ability of a system to perform the functions as expected.

11a) **performance** - How well a system accomplishes its given task using a single set of rules.

11b) **Performance testing -** Consists of measuring the Quality of Service (QoS) or Network Performance parameters, which is traffic dependent. [ATM Forum]

12) **repeatability** - The ability to repeat.

13) **SUT** - The real open system in which the IUT resides. [ISO 9646]

14) **system** - A single device, two or more devices, a single layer protocol, or multiple layer protocols.

Discussion.

The goal is to define and understand the terms: coexistence and interoperability. First an explanation of some terms, including interoperability to put things into place. Second the term, coexistence, will be explained in the context on this background.

The following discussion is based on a network (i.e. ATM) point of view for describing and performing testing. Figure 1 shows the domain of the minimum for each type of test. Conformance has been well defined in ISO/IEC 9646 [1].

The term interoperability has been used extensively, but the definition has not been established for a common understanding. The concept and term operability is fairly new and deserves some discussion.

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           ______(4b)______  _____(4a)_____
          /                \/               \
   ____   UNI   ________   NNI   ________   NNI
  | TE |___|___|Switch 1|___|___|Switch 2|___|___
  |____|   |   |________|   |   |________|   |
  \_______/ \______/\______/ \______/
     (1)       (2)     (3)      (3)
  \________________/\_______________/
        (5)               (6)

   (1) Conformance Testing of User-side UNI
   (2) Conformance Testing of Network-side UNI
   (3) Conformance Testing of NNI
   (4a) Operability Testing of Switch 1
   (4b) Interworking (UNI to NNI)
   (5) Testing Interoperability of TE and Switch 1
   (6) Testing Interoperability of Switch 1 and Switch 2
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Figure 1. Conformance, Operability and Interoperability Testing Domains

Conformance

Conformance testing is defined in ISO/IEC 9646 [1] as testing the extent to which an implementation under test (IUT) conforms to a specification. As shown in Figure 1 items 1, 2, and 3, conformance tests are developed for a particular interface layer.

Conformance testing involves both the capabilities and the behavior of an implementation, and checking what is observed against the conformance requirements to the relevant International Standard or ITU-T Recommendation and if appropriate in the related international standard profile and against what the implementor states the implementation capabilities are.

Conformance testing does not include assessment of the performance nor the robustness or reliability of an implementation. It cannot give judgements on the physical realization of the ASP, how a system is implemented, how it provides any requested services, nor the environment of the protocol implementation. It cannot, except in an indirect way, prove anything about the logical design of the protocol itself.

The purpose of conformance testing is to increase the probability that different OSI implementations are able to interwork. However, it should be borne in mind that the complexity of most protocols makes exhaustive testing impractical on both technical and economic grounds. Also testing cannot guarantee conformance to a specification, since it detects errors rather than their absence. Thus conformance to a test suite alone cannot guarantee interworking. What it does do is give confidence that an implementation has the required capabilities and that its behavior conforms consistently in representative instances of communication.

Operability

ISO 9646 does not explicitly cover or emphasize this type of testing. Operability covers the functionality of an entity or a particular layer within that entity. It includes more than just a single interface, as shown in Figure 1 for Switch 1 in item 4a. It tests a single product (which could be made up of elements from several vendors).

Most, but not necessarily all, test cases should be run in the normal operating environment under normal conditions, as opposed to the extensive error testing done when conformance testing.

Interoperability

When more than one object is involved in communication, there arises the problem of whether together they behave as expected. This is the problem of interoperation in a very general sense. Thus (1) the involvement of more than one object and (2) the objects together behaving as expected are the two key characteristics in (correct) interoperation.

We can define interoperability by saying that two or more objects interoperate if they behave together as expected by the relevant specifications. Within the context of communication networks, an object can be a network node, a layer of a node or a component of a layer or a plane or even an entire network, i.e. anything we decide to view as a whole.

This notion of interoperability and object allows us to see various kinds of interacting behavior within a network and between networks as special kinds of interoperability.

An abstract view of communication can be conceived when network nodes are layered and underlying layers are regarded as the service provider for the layer above as in OSI architecture. Then by similarly viewing underlying layers as the service provider, we can focus on the behavior of a certain layer and think about interoperability of the objects, which realize the particular layer under consideration. In this way, the definition of interoperability remains valid even when we take an abstract view of network nodes and networks.

Depending on the abstract view of objects in the network, there can be different types or views of interoperability. Three views, which draw most attention, are system interoperability, end-to-end interoperability, and interworking.

System Interoperability

System interoperability is defined to be the operation of the system as a whole. This whole system may be as large as to include every object in the network (all items of Figure 1), to as small as only two objects in the network (items 5 or 6 of Figure 1).

Using the ISDN Protocol Reference Model we can view system interoperability in each of the three planes: user, control, and management. One view could be the system interoperability of the control plane (i.e., signalling (UNI and NNI)). Another view could be the system interoperability of the user plane. This view could also be termed end-to-end interoperability, which is discussed in the next section.

Some examples of system interoperability are listed below.

- o System Interoperability at the User plane
  - "services" or "application level" (i.e., LANE, AMS, VTOA, CES)
  - "end-to-end" (more specific than services, or application)

- o System Interoperability at the Control plane
  - signalling (including Q.2931, SAAL) (control plane services: i.e., QoS, SVCs, cell rate, broadband bearer capability, traffic class)

- o System Interoperability at the Management plane
  - ILMI
  - OAM (check if the management functions were performed)(i.e., OAM sent to see if the number of cells received was the number of cells sent)

The ATM layer is used by all of the above planes. For CES, there is a control plane component, as well as a user plane component. PNNI contains a routing part and a signalling part. The PNNI signalling part is part of the control plane, while the routing part may, or may not, be considered as part of the control plane.

End-to-end Interoperability

Often in a complicated network, verification can be easily tried at the final application’s level. This may be called end-to-end interoperability. It abstracts from all the layers beneath and all the nodes and components between the two ends. Thus, the main effect of such verification is to see the interoperability of applications themselves. See Figure 2 below for a minimum set of the testing domains of end-to-end interoperability.

```
   ____   UNI   ________   NNI   ________   UNI   ____
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  | TE |___|___|Switch 1|___|___|Switch 2|___|___| TE |
  |____|   |   |________|   |   |________|   |   |____|
  \___________________________________________________/
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Figure 2. End-to-End Interoperability

By manipulating applications, it is true that certain features of objects in between are exercised and successful manipulation of them gives evidence that the objects in between are probably correct. In contrast to the evidence it gives with respect to the interoperability of applications, the evidence it gives with respect to the interoperability of other objects (such as the underlying service) is only indirect and partial. Also the interoperability of certain combinations of those objects in between the two ends is still a conceivable problem, but remains unexamined in the direct sense.

So the common end-to-end interoperability becomes a special kind of interoperability according to our definition of interoperability and there are still many other combinations of objects between the ends, which we can and should consider for closer and direct examination of correct interoperability.

Interworking

Interworking of two nodes or two networks (which previously could not interoperate), utilizing an interworking function (IWF) unit, becomes interoperability of the three objects, i.e., two nodes or networks with the interworking function unit in between (refer to Figure 3). (It is possible for these three objects to be considered as a single unit, if that is your desired view.) The most common view of interworking is the operation between two networks of different technology specifications (e.g., ATM and Frame Relay). Internetworking is the interworking of two networks (including the IWF).

```
                       ______(1)_____
        ________     /     _____     \     ________
...____| Node 1 |___|___| IWF |____|____| Node 2 |___...
       |________|   |   |_____|    |    |________|
       \_________________________________________/
                              (2)
```

(1) Operability Testing of Interworking Function (IWF)
(2) Testing Interoperability of the system consisting of Node 1, IWF and Node 2

Figure 3. Interworking

Debates

Numerous debates over these terms continue. Below is just a sample.

1) Question: Should interoperability testing include conformance testing?
   Answer: YES-
   If interoperability does not include conformance, then what is the set of rules that the system being tested should follow? Answer: the system is designed to perform a task by following another system's rules. This leads to less interoperability among systems. Being conformant to a set of rules does not guarantee interoperability unless,
   i) there are no options within the set of rules that are mutually exclusive and
   ii) the set of rules is fully specified.
   Answer: NO-
   If interoperability does include conformance, then this becomes a very expensive process because conformance testing, as well as interoperability testing must be done.

2) Conformance testing is expensive.
   Yes, conformance testing is expensive, because it is labor intensive and exhaustive testing is usually not possible.

3) What is the benefit of conformance testing?
It helps to give assurance that the system implements the set of rules. This helps to give assurance that two systems that passed the same conformance tests will interoperate*.

4) Question: How to test for interoperability?
   Answer: Formal tests -
   Advantage- Users can request that these tests are executed and the results are made available. When a test fails, it is easier to discover the problem.
   Disadvantage - Implementors can build systems to pass the formal tests only. Formal tests must be designed, built, and agreed to. Vendors do not want to take tests unless they can guarantee that they can already pass the tests.

   Answer: Informal (closed) tests -
   Advantage - Vendors are more willing to take tests when the results are not available for public review. Can discover items that should be clarified or specified within the set of rules.
   Disadvantage - Every combination of different systems must be executed otherwise all the tests show is that one system can interwork with the other system, not all systems. If a test fails, there is no indication on what caused the failure. Experts on both of the systems, as well as the protocol must review traces to discover the problem.

Performance testing

Performance testing usually consists of testing the limits of an implementation under known/controlled conditions and not necessarily the protocols. For example for an ATM switch, one performance test is to test how fast an implementation can switch ATM cells. This is different from testing the function of an implementation switching ATM cells.

Coexistence

Coexistence implies that two or more things are sharing something. This sharing can cause side effects for the systems sharing that something. ITU-T R.36 refers to coexistence as a comparative performance of a system in a heterogeneous environment to that of the same system in a homogeneous environment.

For a wireless interface protocol the shared something is the frequency band in a given environment.

As given in a Bluetooth presentation it is suggested that at most 10 co-located Bluetooth pico-networks can exist before interference of the pico-nets becomes significant. This means that Bluetooth pico-nets can coexist only if the interference is less than a certain amount. If coexistence is defined in this way, it is based upon some interference criteria. Continuing on this line of reasoning, we need to define the performance requirements (i.e. limits) where coexistence will exist or not.

How to test for coexistence based on performance?
Real -
  Use real systems in the background to create the interference. How to ensure that this real system is a good sample space of the real environment? How to repeat the tests? Repeatability is crucial for testing.
Simulated -
  Use a model that simulates the interference. Need to create this model.

Analogy

Language Analogy:
Shared environment: Audiable human hearing
Set of Rules: American English
Other set of roles: Spanish, British English, Siren.

Conformance - A person's ability to speak the American english language using the rules for American english.
Interoperability - The ability of two persons to carry on a conversation.
Performance - The speed, clarity, volume, or choice of words of the conversation.
Coexistance - The ability of two persons to carry on a conversation while another conversation (english or spanish) is occurring.

Interwork - The ability of an American English person to carry on a conversation with a British English speaking person.

If two persons speak only English and two persons speak only Spanish, then
1) the two persons who speak only english can interoperate, as long as they follow the rules of the english language.
Best conterexample is American English and British english. If one of the only english speakers only speaks British English and the other only speaks American English. The two do not interoperate at 100%. They will for the most of the time be able to interwork. That is they can provide a conversion when necessary. However this can only happen if one understands the other's differences.

2) one person speaking spanish and one person speaking only english can not interoperate. They can interwork, if there is a translator.

3) If both sets are carrying on a conversation, then
i) the english and the spanish conversations can interoperate.
ii) the two conversations can not interwork without a translator.
iii) the english conversation and the spanish conversation can coexist as long as the other converstion does not interfer with the other. For example if the english conversation is so loud that the spanish conversation can not be heard, then they can not coexist.
iv) performance in case iii determines whether coexistance exists.

```
     S
     |
     v
E ->   <- E
     ^
     |
     S
```

4) If a siren sounds during the conversations, the siren can not coexist, since the siren causes none to hear the other. However, if the speakers used megaphones, the conversations and the siren might be able to coexist.

Suggested definitions: Coexistence and Interoperability.

Let coexistence be defined as “The ability of one system to perform a task in a given (shared) environment where other systems may or may not be using the same set of rules.” Determination of whether two systems can coexist with one another will be based on a level of performance for each of the two systems. The “level of performance” is what the Coexistence group needs to agree on.

Let interoperability be defined as “The ability of two systems to perform a given task using a single set of rules.” This eliminates the idea that an IEEE 802.11, Bluetooth, or HomeRF must interoperate at the physical (i.e.

Radio) level, but permits applications to interoperate provided that there is an interworking function that converts at the appropriate level the various protocols. The coexistence group may decide to define the interworking function for each such wireless system.

Application of definitions to IEEE 802.11, Bluetooth, and HomeRF

Assuming the background given above for the various terms, especially interoperability and coexistence, we need to apply these terms to the work at hand.
Need to define the shared environment:
    For IEEE 802.15 WPAN this is the 2.4 GHz radio frequency band.

Need to define the set of rules to be followed:
    For IEEE 802.15 this includes Bluetooth, HomeRF, IEEE 802.11 at least.

Need to define performance metrics for each specification, and, if possible, generic performance metrics, which can be used for any current or possible future specification.
For example:
- Level of interference (Signal to Noise Ratio) before a particular quality of service is violated.
- What quality of service is to be evaluated (e.g. frame, packet, slot, or application (e.g. IP/TCP, voice, video) throughput)
- Number of devices, networks, pico-nets, LANS in a given range.
- Range or area coverage.

Proposals

Adopt the definitions as defined above for coexistence and interoperability.

Define performance criteria for evaluating the performance of the protocols /applications and then use this performance criteria to define the “level of performance” for coexistence based on interference at the wireless interface (i.e. Radio Frequency).

References

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[10] IEEE 802.15-99/088r2, “Coexistence Task Group Charter (power point presentation”, Steve Shellhammer, September 15, 1999