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# From Ontology to Service Discovery in Bluetooth

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## ABSTRACT
*Discovery services in a dynamic environment, such as Bluetooth, can be a challenge because Bluetooth is unlike any wired network, as there is no need to physically attach cables to the devices you are communicating with. Regular Bluetooth service discovery protocol may be inadequate to match different service naming attributes. To support the matching mechanism and allow more organized service discovery, service relation ontology is proposed to extend and enhance the hierarchical structure introduced in the Bluetooth specification. A frame-based approach is used to codify the service relation ontology, which represents the relations of service concepts. A semantic matching process is introduced to facilitate inexact matching, which leads to a situation in which a simple positive or negative response can be meaningful. The semantic matching process improves the quality of service discovery.*

## INTRODUCTION
Bluetooth™ is set to be the fastest growing technology since the Internet or the cellular phone [Bray and Stuman 2002]. Bluetooth has created the notion of a Personal Are Network (PAN), a close range wireless network to set to revolutionize the way people interact with the information and technology around them. Bluetooth is unlike any wired network, as there is no need to physically attach a cable to the devices you are communicating with. In other words, you may not know exactly what devices you are talking to and what their capabilities are. To cope with this, Bluetooth provides inquiry and paging mechanisms and a Service Discovery Protocol (SDP). Service discovery, normally, involves a client, service provider, and seek out or directory server. Bluetooth does not define a man machine interface for service discovery; it only defines the protocol to exchange data between a server offering services and a client wishing to use them. The SDP in Bluetooth provides a means for applications to discover which services are available and to determine the characteristics of those available services [Bluetooth Specification 2001]. However, service discovery in the Bluetooth environment is different from service discovery protocol in traditional network environments. In the Bluetooth environment, the set of services that are available changes dynamically based on the RF proximity of the device in motion.

The Bluetooth SDP uses 128-bit university unique identifiers (UUIDs) which are associated with every service and attributes of that service. However, UUID-based description and matching of services are often inadequate [Avancha, Joshi and Finin 2002]. For example, consider a wireless hotspot such as airport terminal or shopping mall where clients use handheld devices to discover information about available services such as "rail". Using regular Bluetooth SDP, the request may fail if a series of UUIDs stores its service as "metro" or "train" or "bart" etc. In addition, the current version of Bluetooth SDP does not support service registration; the airport information would likely not be able to register its services to facilitate users' needs. Most hotspots services, such as mall, airport terminal etc, are associated with a great amount of more sophisticated attributes than a simple portable device and peripherals service. Using UUIDs to specify requests would lead to a meaningless response.

To tackle this problem and enhance the quality of service discovery, we provide the Bluetooth SDP matching and browsing mechanism to use ontology modeling concepts associated with UUIDs to service in hotspot environments. After introduction, the body of this paper is organized into four sections. The first section provides a brief explanation of Bluetooth service discovery application profile and shows its objectives and supports. The second section focuses on service browsing. A Service Relation Ontology (SRO) is introduced to model the service ontology. A frame-based representation is used to present the service concepts. The third section examines service searching, which describes semantic searching processes. It provides a service records example and also introduces the concepts of service search patterns. The final section discusses the different ontological approaches and shows its advantages and disadvantages.

## BLUETOOTH SERVICE DISCOVERY APPLICATION PROFILE
Service discovery is a process by which devices and services in networks can locate, gather information about and ultimately make use of other services in the network. Service discovery is fundamental to all Bluetooth profiles and is expected to be a key component of most Bluetooth applications [Miller and Bisdikian 2001].

The identified objectives for Bluetooth SDP are:
- Simplicity: Because service discovery is a part of nearly every Bluetooth usage case, it is desirable that the service discovery process be as simple as possible to execute.
- Compactness: Since service discovery is a typical operation to perform soon after links are established, the SDP air-interface traffic should be as minimal as feasible so that service discovery does not unnecessarily prolong the communication initialization process.
- Versatility: It is important for SDP to be easily extensible and versatile enough to accommodate the many new services that will be deployed in Bluetooth environments over time.

SDP supports the following service inquires:
- Search by service class
- Search by service attributes
- Service browsing

## SERVICE BROWSING
Service browsing in Bluetooth is used for a general service search and provides the user with answers to such questions as: "What services are available?" or "What services of type X are available?" In the Bluetooth specification, a service browsing hierarchy is suggested. The hierarchy includes browse group descriptor services records (G) and other service records with (S) [Bluetooth Specification 2001].

### Service Relation Ontology
We propose Service Relation Ontology to extend and enhance the hierarchical structure introduced in the Bluetooth specification. The ontological relation model has been applied to e-Commerce [Lee, Sim, Kwok 2002]. Ontology represents an explicit specification of a domain conceptualization [Gruber 1993]. The classes and relations of the service relation ontology are shown in figure 1, which support *gradation*, *dependence* and *association* classes among concepts. The hierarchical graph illustrates inheritance, where each class on the lower level inherits properties from the preceding level.

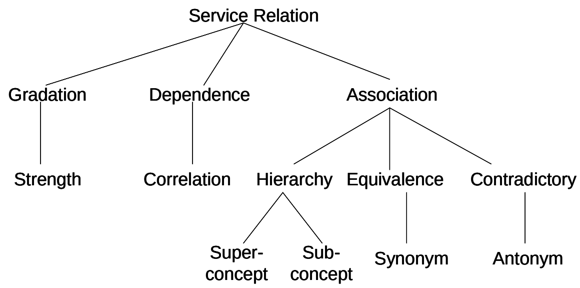


Figure 1. Service Relation Ontology

The three classes identified in figure 1 are:

- Class gradation – to order strength of a concept, which represents a semantic relation for organizing lexical memory of adjectives [Fellbaum 1998].
- Class dependence – to model the semantic dependence relations between concepts, that is correlation.
- Class association – consists of three sub-classes:
  - Equivalence – represents the same concept meaning between or among concepts.
  - Hierarchy – represents the broader or narrower concept relations.
  - Contradictory – represents opposing values of an attribute.

The six ontological relations identified in figure 1 facilitate the effective application of electronic lexicons for Bluetooth service discovery. The operations of the relations are given as follows:

- Super-concept: If a concept has a broader meaning than another concept, then the concept is called super-concept. For example, “audio” is a super-concept of “cellular” and “intercom”.
- Sub-concept: If a concept has a narrower meaning than another, then the concept is called sub-concept. For example, “cordless phone” and “mobile phone” are sub-concepts of “phone” whereas “phone” is a super-concept.
- Synonym: If two concepts share similar properties, then they are synonyms. For example, “cell phone” and “cellular phone” are synonyms.
- Antonym: Of two concepts have opposite properties, and then they are antonyms. For example, “wire” and “wireless” are antonym or “symmetric” and “asymmetric” are antonyms.
- Strength: If a concept is associated with a scale (such as short, square and long) representing degree and grades, then the concept has strength. For example, “decline”, “plummet” and “nosedive” are concepts that are similar in meaning but differ in their strengths.
- Correlation: If a concept is dependent on another concept, then they have correlation. For example, the relationship between bandwidth of a transmission system and the maximum number of bits per second that can be transferred over that system.

### Concept Representation

A frame-based approach is used to codify the service relation ontology, which represents the gradation, dependence and association of service concepts [Lee, Sim and Kwok 2002]. Figure 2 shows an example of a frame and various slots to represent a concept.

<concept>
Service Name: Mobile phone
Property:{ }
Super-concept: {Phone }
Sub-concept: { }
Synonym: { Cellular phone}
Antonym: { Wire phone}
Correlation: { }
Strength: { }
<end_concept>

Figure 2. An example of the service concept representation.

The above service name slot is self-explanatory, both sub-concept and super-concept facilitate categorization, sub-assumption and inheritance. The property slot captures the features, attributes, and characteristics of service concepts. It has the same interpretation as the notion of property of objects in an object-oriented paradigm (OOP). In an OOP, a class of objects inherits prosperities from an ancestor class; in the above formalism, a concept inherits the features (attributes and properties) from concepts that subsume it. The synonym and antonym slots define the (inter-) relations between (and among) concepts with similar or opposite meanings respectively. The correlation slot models depend on concepts. Correlation differs from property because it models the reliance of some attributes of a concept $C_1$ on the corresponding attributes of another concept $C_2$. However, correction does not necessarily imply that $C_1$ is a sub-class of $C_2$, hence $C_1$ does not necessarily inherit every attribute from $C_2$. The strength slot enables service discovery adjectives of different degrees to be compared.

## SERVICE SEARCHING

Service searching in Bluetooth is used to inquire search service by service class and attributes. In particular, when searching for specific service and provide the user with the answers to such questions as: “Is service X available, or is service X with characteristics 1 and 2 available?” [Muller 2001]. However the class of the service defines the meanings of the attributes, so an attribute might mean something different in different service records.

### Semantic Searching Process

Based on the proposed service ontology, we provide a semantic matching process to allow matching different naming attributes. Figure 3 shows the semantic matching process. The key of the searching engine process is a knowledge base, the service ontology, with information about service instances. The searching process first listens to query and extracts service name. It then matches to the service records to determine whether it can answer the query. Upon failure, it responds with no matching message. Otherwise, the engine extracts the relationships that the service ontology describes and uses them to arrive at a service searching pattern solution to a given service discovery query.

### Service Records

A service record holds all the information a server provides to describe a service. Table 1 shows an example of the Bluetooth headset service record [Bray and Sturman 2001].

The example table illustrates how a service record is made up. For example, when a client acquires a “headset” service, the semantic searching engine reaches the service name in the service record. It then goes to the service ontology to get its related concepts, such as its “synonym” concept, earphone. The process continues until the ontology concept frame ends.

### Service Search Patterns

A service search pattern is used to support a list of UUIDs to locate matching service records. A service search pattern matches a service record if

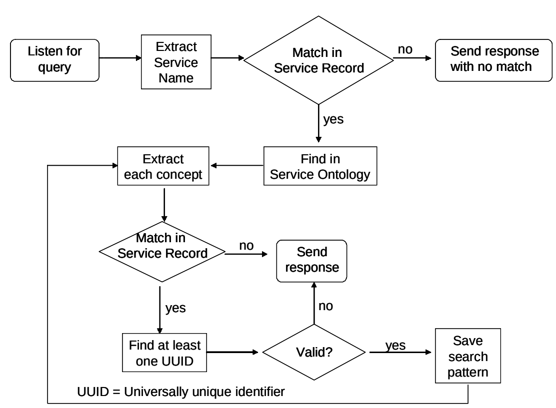


Figure 3. Semantic Matching Process

| Item | Type | Value | Attribute |
|---|---|---|---|
| ServiceRecordHandle | Unit 32 | Assigned by Server | 0x000 |
| ServiceClassDList | | | 0x001 |
| ServiceClass0 | UUID | Headset | 0x1108 |
| ServiceClass1 | UUID | Generic Audio | 0x1203 |
| ProtocolDescriptorList | | | 0x0004 |
| Protocol0 | UUID | L2CAP | 0x0100 |
| Protocol1 | UUID | RFCOMM | 0x0003 |
| ProtocolSpecificParamater() | Unit8 | Server Channel # | |
| BluetoothProfileDescriptorList | | | 0x0009 |
| Profile() | UUID | Headset | 0x1108 |
| Parameter() | Unit 16 | Version 1.0 | 0x0100 |
| ServiceName | String | "Headset" | 0x0000+language offset |
| Remote Audio Volume Control | Boolean | False | 0x0302 |

Table 1. Bluetooth headset service record example (source from: [Bray and Sturman 2001]

each and every UUID in the service search pattern is contained within any of the service record's attribute values. A valid service search pattern must contain at least one UUID. The UUIDs need not be contained within any specific attributes or in any particular order within the service record.

## DISCUSSION

[Avancha, Joshi and Finin 2002] has discussed that using ontology to describe services can facilitate inexact matching because it provides a structure for reasoning about the deriving knowledge from the given descriptions. They have commented that describing service ontologically is superior to UUID-based descriptions. They use the DAML+OIL (Darpa Agent Markup Language and Ontology Inference Layer) to describe their ontology and a Prolog-based reasoning engine to use the ontology. Although DAML+OIL is becoming a standard for use in the semantic Web, the ontology developers may have difficulty understanding implemented ontology or even building new ontologies because they focus too much on implementation issues. Moreover, direct coding of the resulting concepts is too abrupt a step, especially for complex ontologies. In this paper, we provide a language-independent concept model for representing the "context-dependent" classification knowledge. The classification knowledge is to organize words into groups that share many properties. The context is dependent on Bluetooth service discovery concepts.

## CONCLUSION

We have introduced a service ontology concept modeling to enhance the Bluetooth service discovery. We have shown a frame-based presentation to support gradation, dependence and association classes among concepts. The semantic searching process allows matching different naming attributes to increase the quality of service discovery.

We envision the semantic service discovery solution can also be applied to wireless LAN, IEEE 802.11b and wide-area wireless networks. By looking at the rapid deployment of wireless technologies in hotspots such as cafes, shopping malls and restaurants around the world, the semantic service discovery will play an important role in future mobile-commerce applications.

Our future work includes evaluating semantic matching performance both in response time and processing time. We will need to compare the response and processing times for service discovery queries in the enhanced Bluetooth SDP with those in the regular system. We will also investigate the possibilities of developing m-commerce applications using semantic service discovery.

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