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"Web Services and Service Discovery in Military Networks"

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Web Services and Service Discovery in Military Networks

Abstract

Next generation C2 systems must be geared towards NEC. The systems used by coalition forces must be agile and adaptable. Web Services can provide a fundament for an agile system. In NEC, there will be several services available for national and coalition force use. Thus, the service discovery mechanism used in any network must take the capabilities and limitations of the network into account; for instance, in low capacity networks it might be needed to sacrifice flexibility in order to reduce resource usage. Due to the large variation in network capabilities on different operational levels it is unlikely that one can find a single mechanism for service discovery that can be used everywhere. Thus, there is a need for a toolkit consisting of different service discovery mechanisms so that each network can use the mechanism that is most suited for that particular network. However, in a defense scenario, information exchange, and thus service discovery, must be available across network boundaries. This means that the service discovery mechanisms chosen must be able to interact with each other without the need for manual configuration. This paper discusses service discovery in military networks, and suggests an architectural approach to implementing this functionality.

1. Introduction

One of the main goals of Network Enabled Capability (NEC) is to increase mission effectiveness by interconnecting military entities. Sharing information between decision-makers can help guide them towards making the right decisions at the right time, and a common information infrastructure is needed to facilitate sharing of relevant information across system and national boundaries. This leads to a requirement for a flexible, adaptable and agile communication infrastructure which can support all the communication needs of national forces, and at the same time support interoperability. The information infrastructure will have to support a number of different usage scenarios, from fairly static environments where services are stable, to dynamic environments where both services and service users come and go in a non-deterministic fashion.

The NATO NEC feasibility study envisions the concept of a Service Oriented Architecture (SOA) to become pervasive in this information infrastructure. In a SOA, networked resources are made available to others as a collection of services, often implemented using a technology called Web Services. Current Web Service solutions are designed for Internet-type networks where bandwidth is abundant and nodes are stationary. Applying such technology directly for military purposes may not be feasible, especially when considering the tactical level where resources are scarce (low bandwidth) and the network consists of mobile units leading to frequent topology changes.

In a highly dynamic environment, being able to locate and invoke Web Services becomes a major challenge. The process of identifying a service, known as service discovery, is an important part of any SOA, but is particularly challenging in dynamic environments such as military tactical systems. A service discovery architecture for such an environment should reduce the amount of manual configuration, enable automatic discovery and selection of relevant services, and offer a complete and up-to-date picture of the services available at any given point in time. The discovery infrastructure must provide a fresh view of available services. Responses to queries should mirror the current state in the service network and should not advertise services that are no longer present on the network. This is known as liveness information. Moreover, the infrastructure should be robust in terms of partial failure as well as bandwidth efficient, since nodes in dynamic environments may have wireless connections with low network capacity.

2. Service Discovery and NEC

There are two main categories of service discovery models, as classified in [2]:

1. The *client-service model.*
2. The *client-service-directory model*.

The first model does not rely on a registry for service discovery; instead it relies on a totally decentralized topology. In this client-service model a client broadcasts or, more efficiently, multicasts its queries on the network. The services that match the received query return a reply. In this model there is no registry server to keep the information about the services. This model is considered suitable for small networks [2]. In the client-service-directory model, there is a registry that keeps information about all the services which are on the network. This registry can be either centralized or distributed.

A pure client-service-directory model as is currently used in Web Services should probably not be employed in NEC. Service discovery in NEC should support a hybrid model, in which a pure client-service communication model can be used in the absence of a registry service. However, in those cases where a registry is present, one could fall back to using the client-service-directory model. We suggest that the registries should be detectable as any other service, enabling the use of the client-service model until a usable registry service is detected.

When designing a service discovery architecture for NEC, it is important to note that constraints on network availability and topology, available services, intended users and required robustness, all vary with each deployment, and thus add to the complexity of such an architecture.

3. Web Service Discovery Solutions

We can divide existing technologies for Web Service discovery into local area network (LAN) discovery and wide area network (WAN) discovery. However, these current technologies target different domains, and no relationship between them exists.

For WAN discovery, both UDDI [11] and the ebXML [12] registry make it possible to use multiple registries or to let a registry consist of several nodes, which can help achieve robustness and scalability. In UDDI, either replication between registry nodes or a hierarchical model may be used. The ebXML solution supports a non-hierarchical multi-registry topology, facilitating federated queries. LAN discovery solutions such as WS-Discovery [13] are often based on local-scoped multicast. WS-Discovery facilitates registry discovery and local service discovery based on URI matching. WS-Discovery is not suitable for Internet-scale discovery since it relies on multicast. However, since it is only a draft specification at the moment it may evolve to include some of these lacking features in a later version. WS-Discovery could perhaps be used to discover registries in a LAN, or services in a local area if no registry is present, thus complementing UDDI and ebXML.

4. Operational Levels

An operational network is complex (see Figure 1). There are different levels with different communication needs and solutions. It is apparent that a single service discovery mechanism will not meet all demands. At the lowest level, there are a few highly mobile units. Moving up in the hierarchy there will be more units, but less mobility. The command posts are typically deployed tactical networks.

Looking at the different operational levels in context (see Figure 2), we can see that the characteristics vary from level to level. A strategic network has infrastructure and is typically not dynamic.

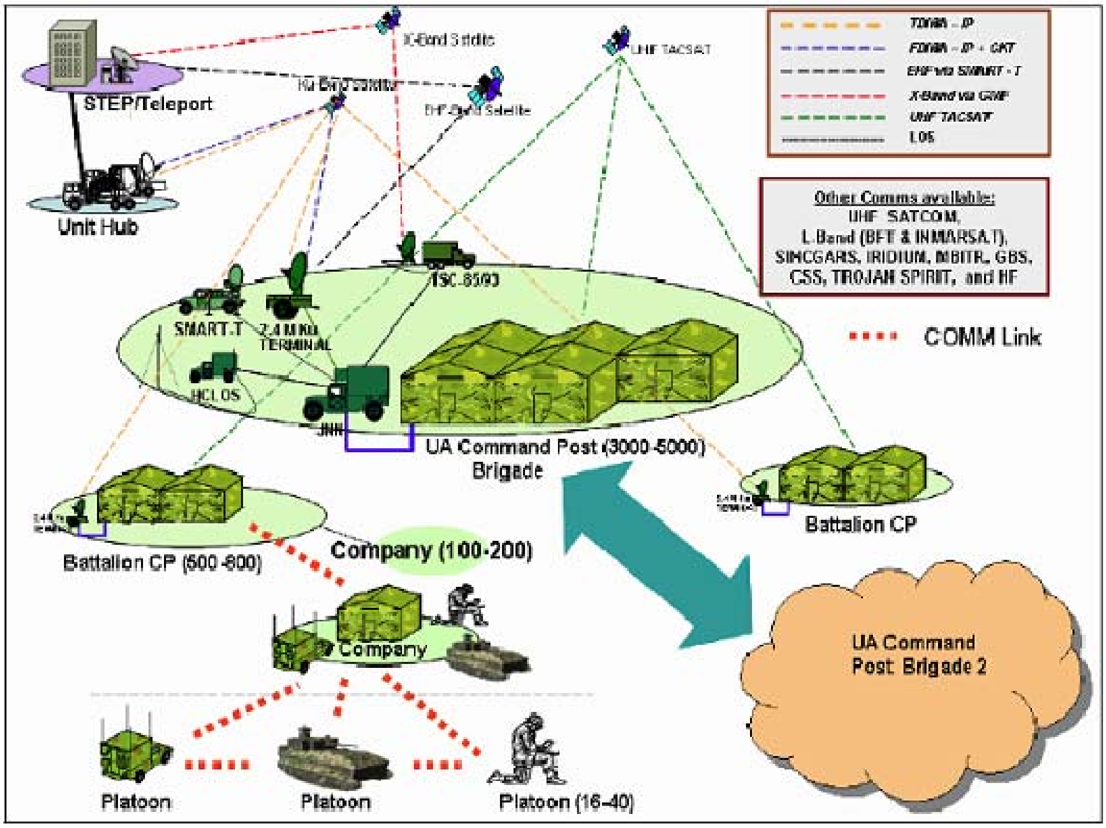

Figure 1 Operational network (from [10])

A tactical deployed network is more dynamic than a strategic network, typically depending on radio or satellite communication. A mobile tactical network, i.e. networked single units taking part in an operation, typically yield the highest dynamicity seen in an operational network. On the other hand, the total number of services available will be highest in strategic networks. The deployed tactical network will have a more specialized need for services, and thus most likely a lower number than on the strategic level. A mobile tactical network will have and use the least number of services. Not only does the limited bandwidth at this level limit the possible amount of services and communication, but also the need for services will be location and mission specific.

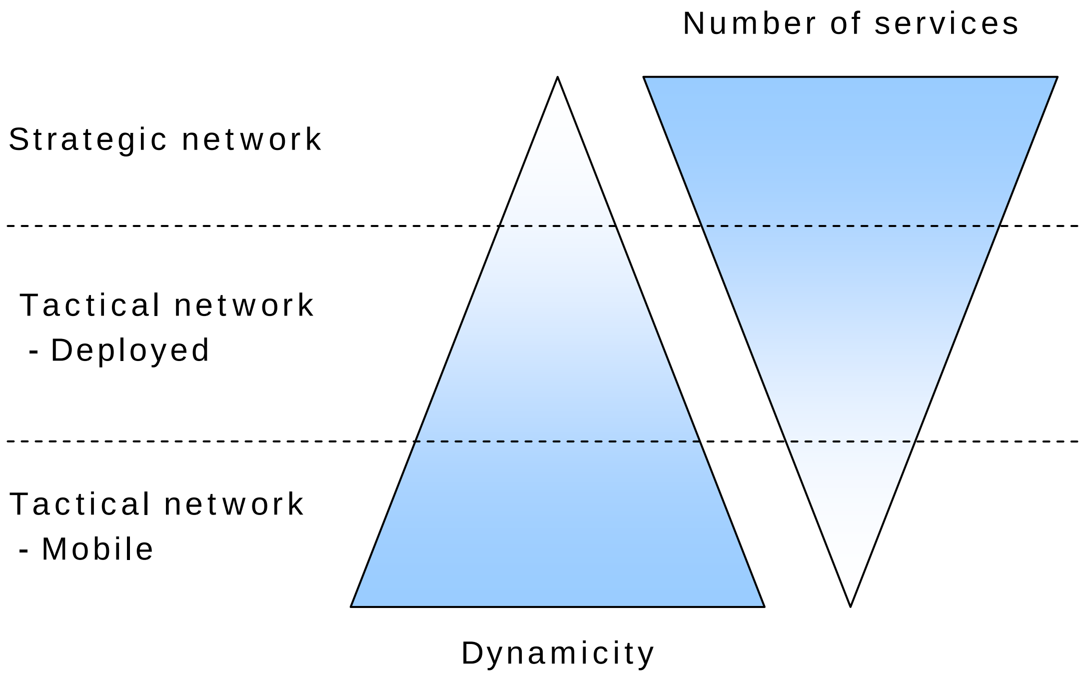

Figure 2 Domain complexity

5. Related work

Previous related work investigates solutions suitable for use at either operational level, but does not look at the different levels in context as we do. However, while these solutions are standalone, experimental and currently not interoperable, they have the potential to perhaps be a part of a multi level service discovery architecture for NEC some time in the future. There are too many service discovery initiatives to mention all here, so we list a few of the more prominent solutions.

Apple's *Bonjour* (formerly Rendevouz) uses a combination of link-local address choosing [3], Multicast DNS (mDNS), and DNS-Service Discovery (DNS-SD). A proposal to use DNS-SD and Zeroconf technology to interconnect soldier wearable computers and Ethernet-enabled devices is presented in [4].

JXTA [7] is a framework by Sun for building peer-to-peer applications. One particularly interesting research project based on JXTA is the Service-oriented Peer-to-Peer Architecture (SP2A) [9]. It currently supports service deployment with Web Services and semantic service descriptions in OWL-S. The peer-to-peer paradigm, coupled with the SP2A concept, seems to be suited for use in NEC from a theoretical point of view.

In [1], Gagnes assesses several methods for discovering dynamic services in NEC. According to Gagnes, current Web Service discovery technologies are not sufficient in such dynamic environments. Especially liveness information, coherence between LAN and WAN service discovery and dynamic registry cooperation is lacking. The paper lists a series of key requirements such as robustness, registry autonomy, liveness information, and pluggable service description models, and a hybrid topology with autonomous, federated, cooperating registries is proposed. Our paper augments these ideas by suggesting a service discovery architecture approach for all operational levels of military networks.

In the battlefield, MANET technology is well suited to meet the demands for dynamic networking. However, limited resources (most notably bandwidth constraints) in such tactical networks call for specialized solutions. In fact, approaches that work in wired networks may well be counterproductive in MANETs [6]. Thus, one should try a different approach to protocol design in such networks. Generally speaking, *cross-layer design* refers to protocol design done by actively exploiting the dependence between protocol layers to obtain performance gains [5]. In [6], it is argued that cross-layer effects are unavoidable in MANETs and occur between all layers. There exist several experimental service discovery solutions for MANETs that leverage cross-layer design in one way or another. One such example is Mercury, which is a service discovery protocol that uses cross-layer interaction between the application layer and the routing layer [16].

Cross-layer approaches demand proprietary solutions and modifications of existing standards, as well as being of limited use if IP cryptography is present. These drawbacks have limited cross-layer service discovery from becoming widespread so far, and might limit its usability in a NEC setting. However, cross-layer solutions have low overhead and should thus be investigated for use in military tactical networks where bandwidth is the limiting factor. Application level solutions may also be feasible at this level, since it is possible to reduce the overhead of Web Services significantly by employing XML compression [14]. If one is capable of utilizing an application level solution then that could be preferable, since architecture violations can have a detrimental impact on system longevity, as has been argued for the case of cross-layer design in [17].

6. Suggested Service Discovery Architecture Approach

A service discovery architecture for military operational systems needs to fulfill a number of conditions, as outlined below:

- Omnipresence: The ability to perform service look-up needs to be available to all units, no matter how or where they are connected to the network.
- Pervasiveness: All service consumers should be able to find all services available as long as there exists a network path from the consumer to the service. It is important to note that “all services available” means all the services this unit is able and authorized to use, as there will exist services that are local to one network, or that the consumer is not authorized to know about or use. In other words, the architecture must support access control and other security measures.
- Flexibility/Adaptability: The architecture must be flexible enough to adapt to scarcity in network resources and other similar limitations, i.e. it must be QoS aware.
- Interoperability: The architecture must support interoperability between heterogeneous networks and across nations in a coalition force, and the solutions should therefore be based on standards.

Further issues regarding service discovery particularly concerning registries are discussed in [1].

No single, currently available service discovery mechanism can fulfill all the demands that a military operational network places on service discovery. Because of this, we suggest an architecture where each operational level can use the service discovery mechanism best suited for that network type. For instance, in a network deployment as the one shown in Figure 1, a service discovery solution consisting of three different mechanisms could be suitable. Such a solution, illustrated in Figure 3, would utilize registries in the strategic network, peer-to-peer mechanisms between deployed units, such as command posts, and ad hoc mechanisms between individual units in the field.

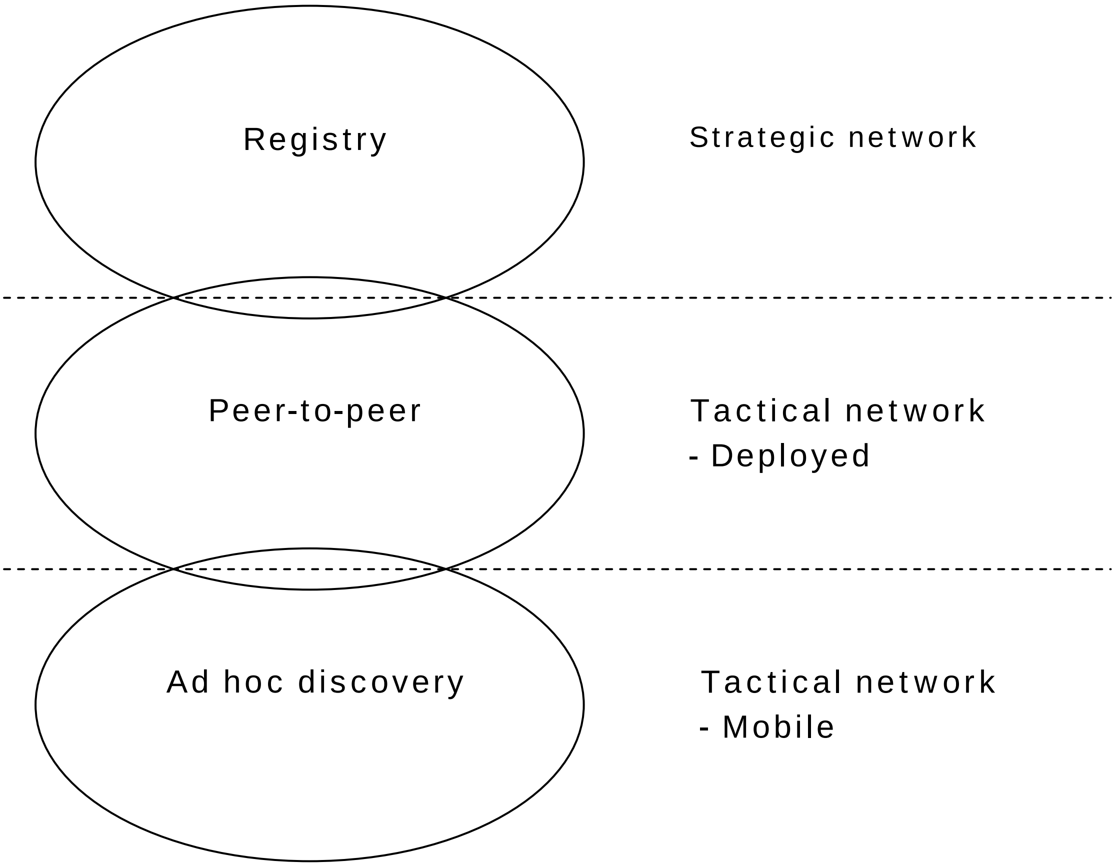

Figure 3 Suggested service discovery mechanisms for each operational level

6.1. Vertical integration

Units in the *ad hoc layer* are typically sensors and services that are mobile. They will primarily need to interact with other services in the same geographical area, but services in other layers should be available on demand. An example of a unit in this layer could be a soldier equipped with simple sensors for localization to keep track of other team members or directions for the current mission. These small ad hoc networks may have limited resources and should use resource friendly discovery methods. Such methods could include *cross-layer discovery* as described earlier. It is important to note that on the lowest tactical level, e.g. within a squad, bandwidth may be less of a problem because higher bandwidth WLAN technology can be used within a short range. The main problem is often the reach back link, which can have a long range and correspondingly low bandwidth.

Contact with upper layers could be offered as a service published by units equipped with the necessary resources to perform the communication. This gateway service, if present, may be used to send queries to a peer-to-peer layer or directly to a registry if available. Typically a query must be sent to a registry if it contains complicated semantics or requires a high degree of accuracy in the results. Other queries may be forwarded to the peer-to-peer-network as results in that layer may be returned more quickly, due to possible value added functionality in that layer. Peers in the peer-to-peer layer may also be delegated resource intensive parts of a query or take care of registry communications before returning the result to the originating unit.

Services in the ad hoc layer are published with a minimal set of descriptions, typically just being based on predetermined identifiers or unique names. Searching will mostly consist of broadcasts with requests for a specific service. More advanced queries are sent to the upper layers through a gateway service.

Above the ad hoc layer is the *peer-to-peer layer*. Typically units in this layer are larger, mobile units that are able to carry more and heavier equipment than the units in the ad hoc layer, thus allowing more resource intensive discovery techniques. Since the amount of resources may vary in each unit, all units in this layer should be able to adapt to the level of available resources – especially bandwidth limitations.

Searching in the peer-to-peer network will depend on resources available in the nodes performing or responding to the search query. Simple semantic descriptions and template based searching should be supported, but need not be used in every search. Due to the overhead of a full semantic search, such metadata should only be used when necessary. Queries originating from units with limited resources in the ad hoc layer will be simple and thus not incur as much overhead as a semantic search. To save bandwidth it should be possible to use previous knowledge gained to complement the queries before the actual search is performed – for instance information about physical location, available resources and so on. Service descriptions should always contain liveness information to enable caching of search results. This allows peers to quickly return frequently requested service descriptions and limits the bandwidth required for communication with the registries.

Units in the peer-to-peer layer should also be able to participate in the ad hoc layer. This enables the peer-to-peer network to discover local services without the need of a registry. In addition, some peers should be able to act as gateways for the ad hoc layer when possible. Peers providing gateway services enable quick and potentially redundant access to the peer-to-peer network for ad hoc layer nodes.

Units in the *registry layer* are stationary service registries and are typically located in local or central headquarters. Communication is primarily based on land lines and high capacity radio links, thus restricting their mobility. Their high bandwidth allows them to cooperate in federations or make use of replication, making them less vulnerable to attacks.

Search queries in the registry layer may have any level of complexity supported by the registry, probably ranging from simple templates to complex semantic searches.

Some registries should be available as a peer in the peer-to-peer layer and as a discoverable service in the ad hoc layer. As a peer, the registry may be able to respond to queries without the need for subsequent connections directly to the registry, thus saving bandwidth. In addition, the peer-to-peer network will allow registries to discover each other. As an ad hoc service the registry can be discovered by passing units, for instance enabling the peer-to-peer network to discover unknown registries when one of its peers is geographically close to it.

6.2. Horizontal integration

In coalition forces today, the various nations have to circumvent their proprietary solutions in order to collaborate. That means that even if they are collaborating in the field, their proprietary radio systems cannot communicate with each other. In order to pass information from one nation to the other, the information must be sent up from the tactical to the strategic level in the nation's network, and then passed through a so-called interoperability point (i.e. a gateway) to the other nation's network, before it is sent down again to that nation's tactical level. Interoperability is currently taking part at the strategic level because communication solutions at this level are based on Internet technology. This solution works, but is less efficient than if the various networks could communicate directly. Direct communication should be achievable in the future considering NATO's current focus on waveform standardization, which would allow interoperability points connecting two different national solutions together using a gateway solution with a NATO waveform. This is an ambition in NEC, and would allow for service discovery between different nations across the same operational level.

6.3. Current Technology Evaluation

Let us now look at the different operational levels in turn, relating possible solutions for each level to current industry standards and current experimental solutions that are still subject to further research.

In the strategic network, which is static and has high available bandwidth and is Internet-like, one can use commercial, off-the-shelf (COTS) products based on standards to accommodate the service discovery needs. Both UDDI and ebXML are current OASIS standards, and implementations are available from several vendors. Both solutions are suitable for business use over the Internet, and should also be usable in a strategic network where there is no mobility and stale data is less of an issue. Both UDDI and ebXML can be configured as federations of registries, thus avoiding having a single point of failure and gaining tolerance to partial failure. From a NATO perspective, interoperability is a very important issue of service descriptions and service discovery. Choosing a common standard for service registries enables NATO partners to be interoperable in operations. Currently the NATO C3 Agency (NC3A) is investigating semantic interoperability through the Interoperability Metadata Registry and Object Store (IMROS) team. UDDI and ebXML are being considered by IMROS, but UDDI is considered to be less suitable than ebXML since it is not designed for semantic annotation functionality. Both UDDI and ebXML are standards under the OASIS umbrella, but UDDI is not as actively updated for future semantic extensions as is ebXML [8].

In a tactical deployed network, on the other hand, the current registry solutions are too static. A solution that scales to thousands of users and yet can handle some mobility is needed. Also, bandwidth is lower than in a strategic network, so federations of fully or partially replicated registries are probably not desirable, even if one could overcome the problem of stale data. At this level there is currently no suitable standardized solution available.

In a mobile ad hoc network there is potentially high mobility, and bandwidth is low. Also, there are few services and few participants in the network at this level. To limit overhead, one should investigate cross-layer service discovery solutions, even when considering the drawbacks. Even though you lose some of the flexibility (and standard compliance) of the service discovery solution by combining it with the routing layer, you gain the ability to express a few pre-defined services and distribute information about them with low overhead. At this level there is also a lack of COTS and standards, so any solution that emerges here is currently experimental. Considering that this is a problem specific to military networks, one solution could be to write a NATO STANAG rather than opting for a civil standard. Also, even if one uses a seemingly stand-alone service discovery mechanism at this level that does not rely on a registry, it should still be able to use a registry (or peer-to-peer service discovery mechanism) when available.

7. Conclusion

In this paper we have provided a theoretical evaluation of current service discovery mechanisms for Web Services. Based on the shortcomings of the existing solutions we have suggested an architectural approach for service discovery. We suggest a hybrid service discovery model for use in military networks.

Considering the technical suitability of current service discovery solutions, we can provide the following theoretical evaluation: Currently, registries are the most mature of the service discovery solutions for Web Services. Both UDDI and ebXML are standardized by OASIS, and provide basic static registry functionality. Due to ebXML's flexibility when compared to UDDI, we suggest that one should look into using that solution for NEC, at least as a registry solution at the strategic level.

Discovery solutions for use in tactical deployed and mobile networks are another issue, and there are currently no clear candidates for use at these two levels. We suggest further experimentation with peer-to-peer and both application layer and cross-layer solutions for service discovery for use on these operational levels.

8. Future work

As we have seen, there are many open issues regarding service discovery in military networks. Future work consists of four main focus areas:

1. Investigating registry solutions
2. Investigating peer-to-peer solutions
3. Investigating ad hoc discovery solutions
4. Investigating interaction and integration
    a. Vertical integration for nation wide utilization.
    b. Horizontal integration for NATO coalition utilization and interoperability.

At the registry level, several initiatives within NATO are currently working on choosing a standardized registry model. The chosen standard will probably have to be extended to support the described architecture.

At the peer-to-peer level, a suitable protocol would have to be created. Today, such systems are generally not very well suited for service discovery in highly mobile, low bandwidth networks. One of the reasons for this is that the search algorithms are usually either quite bandwidth expensive (as in unstructured networks) or too static (as in structured networks) or even both. Ways of delegating resources between nodes and distributed searches should also be looked into.

In the ad hoc layer there would have to be developed an efficient discovery mechanism that can quickly find nearby services, even when bandwidth is extremely limited. The chosen mechanism should allow for a gateway service to provide access to the other layers of the architecture.

Finally, units in all three layers must be able to cooperate with each other and share service descriptions and search methods. Future work on this will depend on standards chosen by NATO and the results from our research.

The architecture would also have to be extended to support security mechanisms required by NATO, an area where more research is needed.

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