Concentris Systems

DSF for MANETs

Distributed Services Framework for Mobile Ad-hoc Networks

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1. Overview

The Distributed Services Framework for Mobile Ad-hoc Networks addresses the challenges of interconnecting a diverse set of operational wireless nodes and making available the services and data published by those nodes in a reliable and efficient manner. It is designed to provide interoperability with key standards required by the Department of Defense's Net Centric Warfare objectives and leverages existing open standards and open source products for integration with both military and commercial applications.

Commercially available services frameworks are targeted primarily towards fixed network infrastructures, including wired and stable wireless networks. Many of these approaches rely upon significant traffic overhead, are not scalable in a delay-tolerant environment, rely on centralized infrastructure, or perform badly when connectivity becomes intermittent. A Distributed Services Framework that overcomes these challenges can greatly accelerate the objectives of the Department of Defense *Joint Vision 2020* initiatives.

The DSF for MANETs system provides a framework to enable efficient and reliable distributed services on wireless networks with characteristics typical of MANETs. The DSF is not an end-user application, but rather an underlying "kit" with which military and commercial developers can implement reliable, distributed, service-oriented applications intended to operate on inherently unreliable mobile, ad-hoc, wireless networks.

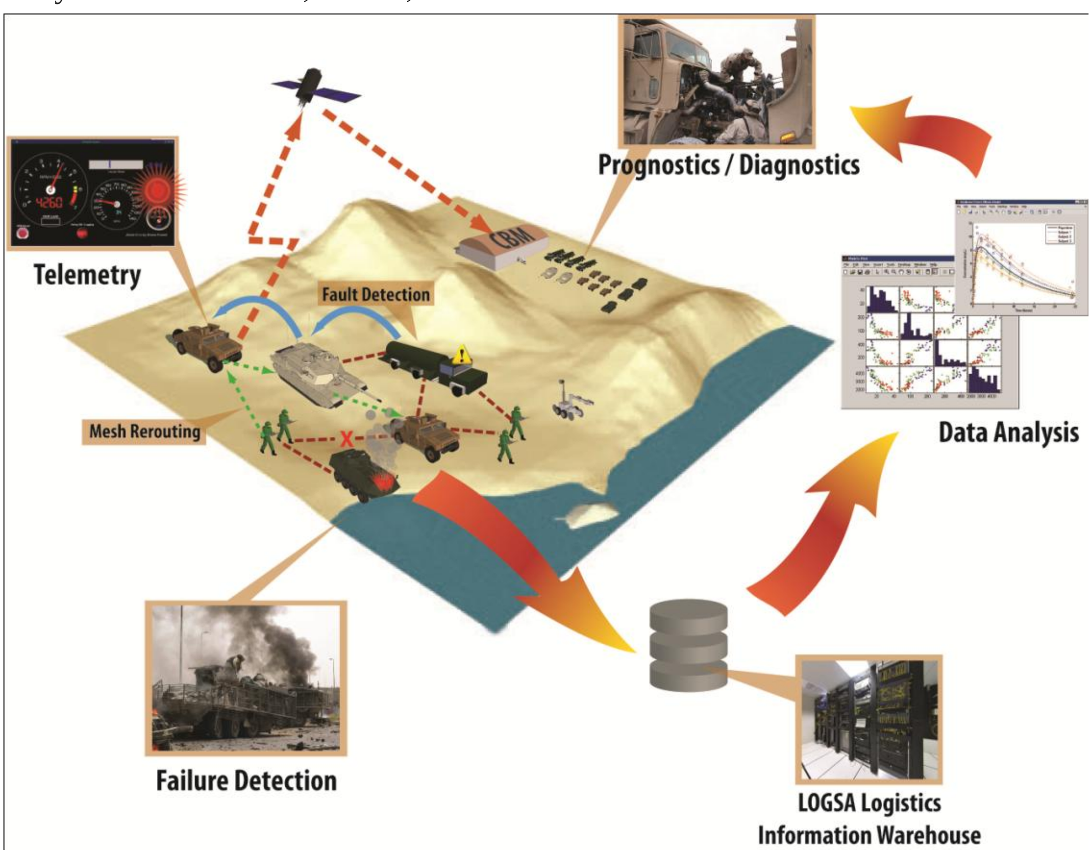


Figure 1. DSF for MANETs OV-1: The DSF for MANETs will provide a robust framework to enable a diverse set of distributed services related to prognostic and diagnostic data collection and analysis, as well as specific enhancements for reliable operation over an unreliable, resource constrained network.

2. Background

As mobile devices and wireless communications have proliferated at an unprecedented rate, MANETs have become the subject of intensive research over the past decade. The objective of seamlessly connecting a multitude of diverse platforms on a large scale remains challenging.

A MANET, sometimes called a mobile mesh network, is a self-configuring network of mobile devices connected by wireless links. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, and therefore be a router. The primary challenge in building a MANET is equipping each device to continuously maintain the information required to properly route traffic.

A distributed services framework provides methods for systems development and integration where systems packages function as interoperable services. A DSF infrastructure allows different applications to exchange data with one another. The DSF aims to ensure a loose coupling of services with dependent libraries, operating systems, and platform resources, and to separate functionality into distinct units, or services, which are made accessible over a network for the purpose of recombination and reuse in end-user applications. These services communicate with each other by passing data from one service to another, or by coordinating an activity between two or more services. On a broad scale, interoperability between differing administrative groups of cooperating services and applications is known as a System-of-Systems architecture.

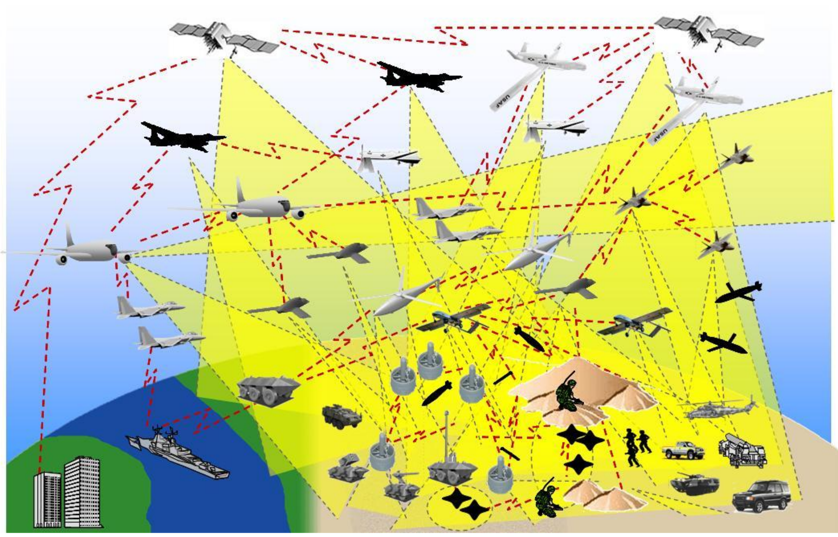
A System-of-Systems architecture must effectively deal with various issues, including:

- **Crossing Trust Boundaries** where each system is controlled and managed independently, and is subject to social, political and business considerations;
- **Managing Quantitative and Qualitative Differences** in data exchange and performance – for example an “edge” system often carries time-critical data at high rates, some of which must eventually trickle into an “enterprise” system;
- **Operating across Disparate Technology** stacks, design paradigms, and life-cycles of the different systems;
- **Incremental and Independent Development** arising from the fact that systems are generally developed and evolved independently;
- **Impedance Mismatch** arising from the non-functional differences in the information exchange between systems – both in the quantity and the quality of the data exchange;
- **Dynamic Real-Time Adaptation** arising from the fact that the environments can change dynamically, and it is not practical to have a centralized administrator or coordinator;
- **Scalability and Performance**, arising from the need to support additional dependencies and resources as more systems are introduced.

2.1. The Current Situation

The Department of Defense (DoD) *Joint Vision 2020* initiatives aim to create a force that is dominant across the full spectrum of military operations through information superiority. This objective is dependent upon the potential of networking geographically dispersed combat elements. In doing so, the Army expects to achieve significant improvements to shared battlespace understanding and increased combat effectiveness through synchronized actions. This Joint concept of operations is Network Centric Warfare (NCW).

NCW relies increasingly on Systems of Systems characterized by thousands or more platforms, sensors, decision nodes, actuators, and operators connected through heterogeneous networks to achieve information superiority in pursuit of mission objectives. The networks, operating systems, middleware, and applications that populate these systems are diverse, but must remain interoperable for successful implementation of the NCW objectives.



"It is not yet clear if or when the information network that is at the heart of the FCS concept can be developed … risks include network performance and scalability, immature network architecture, and synchronization of FCS with Joint Tactical Radio System and Warfighter Information Network-Tactical programs"

GAO Report to Congress April 2008

Figure 2. Scaling the operational network remains a key but daunting challenge for Mobile Ad-hoc Networks.

NCW concepts like the Global Information Grid (GIG) and Net-Centric Enterprise System (NCES) are intended to organize and coordinate this large technology space to provide planners and war fighters with the right data at the right place at the right time across a range of enterprise 'business' systems and battlefield tactical systems.

The DSF for MANETs is designed to address the challenges of interconnecting a diverse set of operational wireless nodes and making available the services and data published by those nodes in a reliable and efficient manner. Additionally, it provides interoperability with key standards required by the DoD's NCW objectives, and it leverages existing open standards and open source products for integration with both military and commercial applications. This framework can greatly accelerate the implementation proposed by the DoD's *Joint Vision 2020* objectives.

3. Justification for Change

Robust and efficient distributed service provisioning over MANETs requires enhanced support for service advertising, discovery and invocation. Current service discovery protocols are mainly targeted towards fixed wired infrastructure or relatively stable cellular wireless networks. Many of these protocols create significant traffic overhead, are not scalable in a wireless environment, rely on central infrastructure, or perform badly when connectivity becomes intermittent. The proposed DSF system will include defining methods for the hosting, discovery, description and invocation of services across unreliable wireless links and the design of a distributed substitute for a central directory services that will not significantly consume available bandwidth, processing and storage resources.

Existing distributed services frameworks and service oriented architectures are not designed to degrade gracefully under conditions that are typical of MANETs. Such architectures generally make a variety of assumptions regarding parameters of the network that break down frequently in a MANET, such as:

> **The network is reliable.** Wireless networks are inherently less reliable than wired networks, especially in hostile radio frequency (RF) environments or networks that incorporate a large order of actively communicating nodes (spectrum saturation).
>
> **Latency is zero.** As MANETs are typically composed of a large number of randomly (or unpredictably) dispersed nodes, communication often involves several hops for data to travel between a pair of communicating nodes. In such cases, physical transport latencies can reach orders of several seconds.
>
> **Bandwidth is infinite.** Again, due to the wireless nature of MANETs, bandwidth is typically limited and varied compared to traditional wired, switched networks. Though the theoretical bandwidth of wireless networks is often larger than typical wide area network (WAN) bandwidths, nodes in MANETs must contend for a shared bandwidth which must be managed effectively.
>
> **Topology doesn't change.** Traditional networks are fixed in nature, in the sense that one or more physical routes between any two devices are established and unvarying outside of a catastrophic system failure. Typical MANETs can have a diverse mixture of fixed nodes and mobile nodes moving relative to each other in a non-predictable manner. In this environment, routes between devices can change very frequently.
>
> **Transport cost is zero.** Traditional networks are generally composed of powerful clients and servers connected through advanced network switches and routers. These types of devices have sufficient processing and memory resources to transparently access the network layers and transport data. MANETs, on the other hand, are largely composed of embedded, hand-held, and other low resource devices which can suffer from memory or processor starvation during high network loads.
>
> **The network is homogeneous.** Although typical networks are somewhat non-homogenous, they are typically planned and well managed. The ad-hoc nature of MANETs tends toward a very non-homogenous topology; nodes are randomly dispersed geographically, nodes have varying resources available, nodes have varying connection quality, and topologies can create bottlenecks in the communications infrastructure.

In addition to the challenges posed by the characteristics of MANETs, service clients require a mechanism to locate a service provider. This is typically accomplished though a global service catalog that is maintained by one or more servers. The topology and dynamic nature of MANETs create the requirement for a different approach to service provisioning and discovery that will function reliably and predictably in a peer-to-peer network.

Thus the overall justification for change is to provide a more reliable foundation for distributed applications on mobile, wireless networks, allowing for the development of a new class of applications software for MANETs.

4. DSF Concepts

Robust and efficient distributed service provisioning over MANETs requires enhanced support for service advertising, discovery and invocation. Commercially available services frameworks are targeted primarily towards fixed network infrastructures, including wired and stable wireless networks. Many of these approaches rely upon significant traffic overhead, are not scalable in a delay-tolerant environment, rely on centralized infrastructure, or perform badly when connectivity becomes intermittent. Concentris' DSF for MANETs can provide application developers with capabilities for the hosting, discovery, description and invocation of services across unreliable wireless links and provide a distributed substitute for directory services that remain functional even in a delay- or disruption-prone network.

The DSF for MANETs can provide military or commercial developers with a new capability to effectively utilize network and computational resources in a heterogeneous, disruptive environment. Developers using the framework will be able to rely on the DSF to:

- Manage identification, addition, and removal of services without affecting other existing services;
- Access a Distributed Service Catalog and Service Discovery Protocol;
- Provide platform independence - the use of different operating systems and platforms;
- Operate on resource-limited platforms;
- Clearly define functional boundaries in the underlying publish-subscribe technology;
- Provide network abstraction - allow the network topology to evolve over time;
- Share invocation signatures and message schemas but not service internals;
- Develop a structure for service compatibilities and policies;
- Create a method to control session and identity management;
- Build in a metric to allow optimization of DSF performance based on traffic overhead, closeness of destination service node, and other parameters.

4.1. DSF Technology

The DSF for MANETs is based largely on existing industry open standard architectures – specifically the data-centric publish/subscribe architecture represented by OMG DDS specification version 1.2 and the service container framework described by OSGi specification release 4. Building on top of these proven framework specifications, the following DSF components enable a service-oriented application based on the DSF development kit to operate successfully on an ad-hoc network.

4.1.1. Distributed Service Directory

A traditional services framework typically relies upon one or more centralized servers to provide a catalog of available services for client applications. In such an environment, service clients must be able to locate and contact the directory server in order to publish or locate services on the network. As MANETs present an inherently dynamic, peer-to-peer topology, it is unreasonable to assume that a specific server will always be available. In such an environment, a mechanism must be implemented that allows each node to publish its services to neighbor nodes and to learn of services published by other nodes.

Concentris achieves this in the Distributed Services Framework by integrating the local OSGi services container with the distruption-tolerant communication channels provided by DDS. The objective of these changes is to allow for transparent loading of existing OSGi applications into the distributed service catalog without requiring changes to existing software.

4.1.2. Software Provisioning Framework

A major challenge in very large scale mobile networks is software provisioning. The OSGi framework is designed to automatically resolve software dependencies when a service is activated, however, the activation fails with an error if all required bundles are not available on the local node. DSF enables bridging between this local dependency-resolution process and the mesh network, enabling nodes to locate and install dependencies from nearby neighbor nodes.

4.1.3. Binding of OSGi Services to DDS

DDS publish and subscription services provide for a peer-to-peer model of data production and consumption. In order to facilitate the development and deployment of DDS publisher applications, DSF can deploy pre-developed OSGi services via the OSGi framework and adapt a given service API to interoperate on the DDS data bus.

4.1.4. Proactive Network Topology Management

Because MANETs are inherently dynamic networks, a high rate of topology change is expected. Unfortunately, as the topology changes, the network may be bisected, the network may merge with another network, individual nodes may be added or dropped, and “routing costs” will change frequently. Such topology changes entail frequent service catalog changes at each node, and would typically result in bandwidth saturation in moderately volatile networks. However, integration of the low-level topology structure with the DSF service catalog allows for the framework be proactive about dealing with network errors, instead of passively waiting to deal with topology changes.

4.1.5. Implement Pseudo-Multicasting of DDS data

Optimally, when a data publication has multiple subscribers, the data should be multicast on the network to minimize traffic loading. However, current mesh routing protocols and 802.11 wireless networks in general are not well suited to traditional multicast algorithms. In order to minimize the traffic load on the MANET, the DSF project includes components under development to republish (forward) consumed data to nearby neighbors if the framework determines this to be the optimal situation.

4.1.6. Extend DDS Quality of Service Infrastructure

The DDS specification provides a thorough and robust QoS infrastructure. The new functionality above, however, creates new classes of data that can be more appropriately managed with “extended” QoS types in the DDS. For example, it may be desirable to only accept data from the originator, rather than from a multicast proxy. Additionally, it may or may not be acceptable to accept “stale” data from a proxy source, depending on the availability of the originator. Extensions to the existing DDS QoS meta-data allow for a finer grain of control in such cases.

5. Summary of Impacts

A service-oriented architecture that works well on a disruptive network will support the DoD's desire to maximize the use of wireless services, offering the promise of services at any time, in any place, and on any platform. The Concentris DSF is intended to be the service-oriented framework for mobile ad hoc networks that will realize this vision. This project provides methods for the hosting, discovery, description and invocation of services across unreliable wireless links and the design of a distributed substitute for central directory services that will not significantly consume available bandwidth, processing and storage resources.

The DSF for MANETs will offer a significant improvement to conventional services frameworks by providing robust, non-centralized, fault-tolerant, light-weight and secure distributed services management in an unreliable wireless environment. This framework can be used in a variety of both commercial and military applications such as:

- Diagnostic/prognostic services
- Convoy voice/data communications
- Authentication
- Road security
- Fleet management
- Traffic control
- Multimedia
- Vehicle monitoring and maintenance
- Distributed computing
- Distributed storage
- Fault tolerant redundant applications

The DSF for MANETs proposed by Concentris will benefit the Department of Defense and commercial customers by:

- Providing a framework that performs well in realistic wireless environments
- Providing a means to loosely integrate distributed sensors, processors, databases, and communication gateways in mobile convoys or other tactical environments
- Better utilizing valuable and limited resources (processing, memory, bandwidth) of wireless and mobile devices
- Defining a system engineering methodical approach to documentation, workflows, specifications and software components in such an environment
- Utilizing an open-architecture that will improve adoption and integration

For more information on Concentris Systems or the Distributed Services Framework for Mobile Ad-hoc Networks, please visit us online at http://www.concentris-systems.com.