COMMUNICATIONS ENHANCEMENTS FOR FUTURE NETTED SENSORS

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ABSTRACT

The paper describes recent research into communications requirements and novel solutions for future netted sensors or NEC subnets. The key requirements for future netted sensors are described in terms of the data bandwidths and latency required to support the various levels of sensor data sharing and fusion (data, plot and track). To establish how these requirements can be fulfilled a range of advanced wireless and network communications options are described and assessed to determine their performance impact, in terms of efficiency and latency, on the overall system. Based on these results, recommendations are presented for future netted sensor or NEC architectures for future military defence applications.

Keywords: netted, sensor, military, defence, NEC, network, enabled, capability, CEC, cooperative, engagement, centric, tactical, weapon, battlespace, naval, distribution, system, architecture, homogeneous, heterogeneous, disparate, cooperating, distributed, IFF, MFR, IRST, RESM, ESM, ECM, search, electronic, surveillance, fusion, fuse, data, raw, detection, plot, track, coherent, incoherent, airborne, radar, radio, link, communication, communicate, wireless, network, enhancements, security, jamming, ad-hoc, mesh, hybrid, phased, array, antenna, latency, efficiency, COTS, MOTS, real-time

INTRODUCTION

The successful detection, tracking, location, mitigation of electronic countermeasures (ECM), classification and hence engagement of ‘difficult’ targets and asymmetric threats in highly cluttered littoral environments will depend on [1, 2, 3 and 4]:

- Networked, distributed, surveillance and reconnaissance capabilities;
- Data processing and fusion of data (i.e. levels of sensor data sharing) from disparate sensors and matching sensors on different platforms;
- Low-observable detection technology;
- Advances in radar sensor performance.

In this paper the communications requirements and innovative solutions for a homogeneous network of cooperating distributed Multifunction Radar (MFR) are described. In the past, inter-platform sensor data sharing has primarily occurred at the track and plot levels. In this paper we consider innovative solutions designed to support all primary levels of data sharing and fusion (raw radar, phase coherent, detection, plot and track).

The communications requirements and solutions for a heterogeneous network of cooperating distributed netted sensors - Multifunction Radar (MFR), Infra Red Search and Track (IRST), Radar Electronic Support Measures (RESM) and Airborne Radar – designed to support the various levels of data sharing and fusion (data, plot and track), are also highlighted at this point for completeness but have been considered in detail elsewhere by Roke Manor and are not part of this paper.

The paper describes the interfaces between the Multifunction Radar (MFR) sensors and the sensor integration nodes. The paper then presents the data bandwidth and latency required to support the various levels of data sharing and fusion (raw radar, phase coherent, detection, plot and track).

The LASSI Simulator, developed by Roke Manor, is also described in the context of netted sensors. LASSI was used to carry out the modelling, simulations and performance evaluations of the netted sensor or NEC subnet architectures described in this paper.

The wireless radio link technology and network communications options are described and assessed to determine their impact on the performance of the netted sensor / NEC subnet overall system. In particular the efficiency and latency of the various system links are described for each solution. The impact of realistic performance on the overall system is then assessed and recommendations for future netted sensor or NEC subnet architectures are described.

Clearly, the radio link and network technology that integrates the layered capabilities will require very high bandwidth, low latencies and high efficiencies so that data and information are delivered when and where needed at an acceptable system cost.

COMMUNICATIONS REQUIREMENTS OF NETTED SENSORS / NEC SUBNET

This section of the paper presents the data bandwidth and latency requirements for the different levels of data sharing for a future generic Multifunction Radar (MFR) sensor type.

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Future MFR Sensor Architecture

The generic simplified model architecture for a future naval MFR is shown in Figure 1. The figure depicts the different levels of data sharing for the architecture.

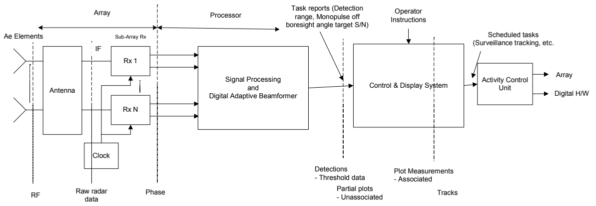

Figure 1: Future naval MFR architecture diagram showing data sharing levels

Requirements for Future MFR Sensor

The calculated data bandwidth requirements for each of the levels of data sharing illustrated in Figure 1 are given in Figure 2 data sharing taxonomy diagram.

• Tracks	100 kbps
• Plot Measurements	
– Associated	60 kbps
– Unassociated	-
• Detections	
– Thresholded data	200 kbps
• Coherent data	
– Phase	1.5 Gbps
– Raw radar	-
– RF	-

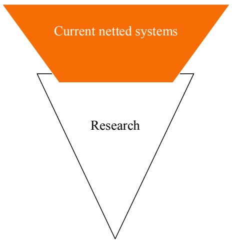

Figure 2: Future naval MFR data sharing taxonomy

It is clear that the most demanding communications bandwidth requirements are at the lowest level of data integration, i.e. the first point in the sensor signal processing chain. From an MFR data communications study perspective, the taxonomy shows the focus is satisfying the bandwidth requirements at the level of unassociated plots, detections and below (primarily prior to plot collapsing in the signal processing chain). The signal processing latency for the MFR sensor was determined to be nominally 200 ms.

NB: a simplistic radar model (Figure 1), which employs digital beamforming, has been used in calculating data bandwidths for the future naval MFR sensor. The information provided should be interpreted as being 'representative of the expected data rate'.

Data Structures & Packets

Data generated at each of the levels of data sharing given in Figure 2 is then used as the payload of a data packet for transmission over the netted sensor system. For example, at the detection level we then have the data packet frame form given by:

- 476 bits (Preamble) + 24 bits (Header) + 748 bits (Data) + 6 bits (Tail) + 15 bits (Pads) = 1269 bits (or approximately 160 octets).

At the low levels of data sharing (coherent and raw radar) the overall packet size will be increased due to the higher data bandwidths resulting in an increase in the data packet payload size.

LASSI SYSTEM SIMULATOR

Description of LASSI Simulator

The LASSI Simulator, developed by Roke Manor, was used to carry out the performance evaluations of the potential netted sensor or NEC subnet architectures. LASSI - Low lAtency Secure inter-Ship communications.

Its main purpose is to facilitate the study of network performance, including network delay and efficiency, for mobile and fixed networks communicating over a variety of radio links. The current version provides a display showing ship positions and radio links and is also capable of showing the evolution of the network of radio links over time in an animated manner. The main features of version 3.0 of the simulator are:

- A GUI based windows simulation application;
- Object oriented design in C++;
- Simulation scenarios described in ASCII text files;
- Display of real-time delay statistics in a separate window based on target node selected by user;
- Output files capturing the key simulation results and parameters of interest to the designer;
- Network routes described in a user selectable ASCII text file;
- An external event file in ASCII text format describing events for specific nodes;
- A simulation dialogue window allowing users to set certain simulation parameters.

Source Models

The selected model represents a jittered packet level source using the negative exponential distribution from which is drawn randomised inter-packet arrival times. It is parameterised by the following two variables:

- A constant packet size (in octets)
- The mean value of inter-packet arrival time.

Thus for a given desired data rate of X Kbit/s with a fixed packet size of Y octets, the mean inter-packet arrival time (IAT) in ms is given by:

$$IAT = {Y * 8}/{X} \qquad \textbf{Equation 1}$$

Source models are treated as separate nodes in the simulation so that multiple combinations of sources can easily be modelled on a single platform (such as MFR, IRST, RESM and Airborne Radar sensor types).

Scenario Input File

The scenario file format describes the set of nodes within the simulation scenario, their position, velocity, sensor range, radio-communications or wireless link technology and network topology. The network topology is described in terms of a list of neighbour nodes and the radio technology used to connect the nodes for communications purposes.

The file format is illustrated in Figure 3. The file is an ASCII text file composed of one line for each node (ship or plane) in the scenario.

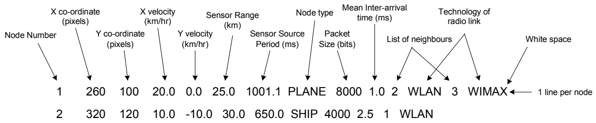

Figure 3: Scenario File Format

The radio technology is a key word taken from the following list of models:

- GENERIC – governed by generic radio technology parameters set in simulation parameter window;
- INTERNAL – internal platform connection used for connecting sources to a platform node;
- WLAN11 – Wireless LAN COTS technology (802.11b - 11 Mbit/s);
- WLAN54 - Wireless LAN COTS technology (802.11a/b/g - 54 Mbit/s);
- WIMAX – Worldwide Interoperability for Microwave Access COTS (802.16 - 75 Mbit/s);
- UWB – Ultra-wideband COTS (IEEE 802.15.3a <500 Mbit/s, 15.4a <10 Mbit/s, 15.3c >1 Gbit/s);
- THZ – Terahertz Communications postulated as a future wide bandwidth technology (100 Gbit/s);
- OPT – Free space optical communications (1 Gbit/s);
- MW/MMW - Microwave / Millimetre-wave technology (802.15.3c – 1 Gbit/s short range);
- L8 – Link 8 technology (based on generic COTS IEEE 802.11b - 11 Mbit/s);
- FDD16 – Broadband Radio Access Links (based on IEEE 802.16 enhanced COTS technology - 1.5-120 Mbit/s nominal, 50-1000 Mbit/s MIMO, 10 ms latency) [5, 6, 7 & 8];

Each of the defined radio technologies equates to a radio link bandwidth and latency metric which are currently coded as part of the LASSI application.

SIMULATION SCENARIOS

This section describes the different simulation scenarios of relevance. Three main netted sensor or NEC subnet architectures were considered and these are described.

Broadcast (Fully Meshed)

In this scenario we assume a fully-meshed all informed network where the source data from each sensor (source) is broadcast to all other nodes (platforms - ships, helicopters or planes) in the network. In this context broadcast either means broadcast in an omni-directional sense or via specific steerable beams for each receiving node.

Routed Point-to-Point (Ad Hoc)

This scenario is in many ways the exact opposite of the Broadcast scenario. All radio communications links are treated as point-to-point. If there is no direct path between one node and another, data must be routed through one or more intervening nodes.

Hybrid Network (Mixed Broadcast and Routed)

A hybrid network is a mixture of broadcast domains and routed domains. Broadcast domains provide low latency, high fan-out for a set of edge nodes (those nodes that only source and sink data). Nodes at the centre of a broadcast domain act as router passing data flows from one domain to other connected domains.

Homogeneous Network of MFR Sensors (Scalability Simulations)

These simulations considered how the different (broadcast or routed) models scale with number of nodes. We focused on homogeneous networks of 5, 10 and 15 nodes each with an MFR sensor operating in the detection data sharing mode in order to determine the scalability trends. We focused on analysing the data structure at the relatively important detection level for each sensor because the detection level of data sharing is considered to be of highest priority. The Link 8 (11 Mbit/s) was chosen as the radio technology best matched to the data rates concerned at the detection level.

An example network for 15 nodes with 3 radio links per node is shown in Figure 4 This network and its routing file were automatically generated from the scripts previously described.

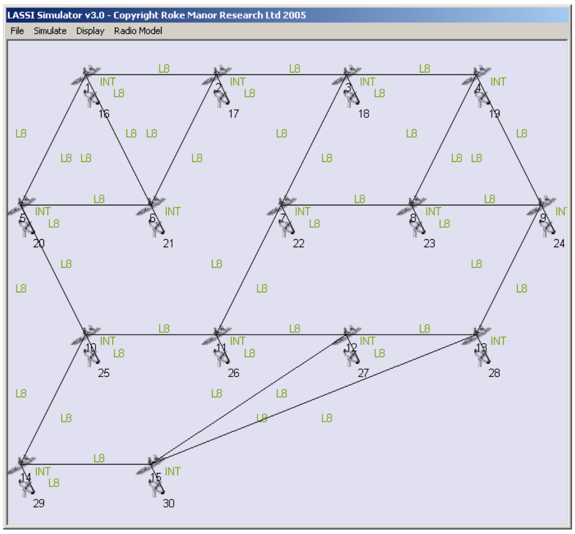

Figure 4: Routed Network of 15 Nodes with 3 Radio links per Node

Homogeneous Network of MFR Sensors (Scalability Simulations)

In order to evaluate the hybrid network approach, three hybrid networks of nodes, each with a single MFR sensor per node, were created. The scenarios considered included 5, 10 and 15 nodes respectively. The 10 node network is displayed in Figure 5. In this case, nodes 5 and 6 are core network nodes each with a broadcast topology to their local edge nodes (nodes 1, 2, 4 and 8 in the case of node 5 and nodes 3, 9, 10 and 7 in the case of node 6).

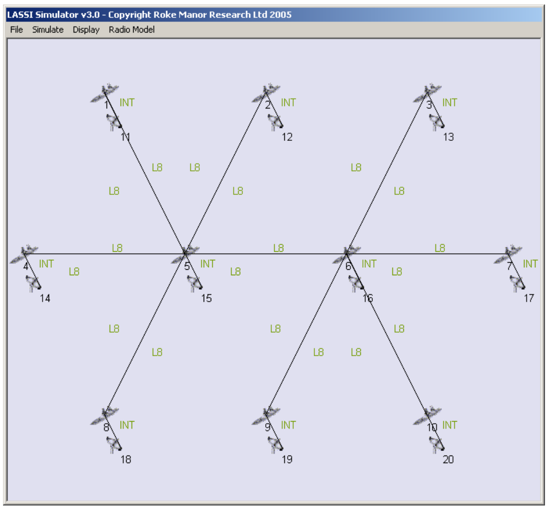

Figure 5: Hybrid (Broadcast and Routed) Network of 10 Nodes

SIMULATION RESULTS

The results of simulations carried out on the routed, meshed and hybrid networks of MFR sensors are presented in this section. The MFR sensors are operating at the detection level each generating an average data bandwidth of 200 Kbit/s. The simulations consider the network related delays from source to receiver in order to compare different network scenarios for performance reasons. Total end-to-end delays are greater when specific compression/decompression schemes are used.

The main performance criteria that are reported on are:

- Average Delay: This is the average network layer delay from sensor to receiving node. It is average over all data flows and over the duration of the simulation run;
- Maximum Delay: This is the maximum delay observed between sensor and any receiver during the simulation run;
- Efficiency: This is defined as the average amount of bandwidth actually used divided by the total bandwidth available in the complete network. It is therefore a measure of how well utilised the radio resource is for the particular scenario being studied;
- Radio resource per node: This is the average number of radio transceivers required per node in the scenario. It forms a measure of how cost efficient the topology is in terms of radio link communications equipment.

All simulations performed were run for a length of 500 seconds of simulation time. This period is sufficient to account for the statistical fluctuations in traffic sources and for the system warm-up period. The system warm-up period is defined as the time taken for all data flows to be passing completely through the system and for the queues to reach an average operating point (fill state).

Homogeneous Network of MFR Sensors (Scalability Results)

Figure 6 and Figure 7 shows the average and maximum delay, respectively, experienced (at the networking level and therefore ignoring any application level compression/decompression) by packets of data sent from one sensor and received by another node. In the case of the routed network the delays increase due to the larger number of hops that the data must travel (on average) between any two nodes. In the hybrid network, average delays are larger than the meshed network but limited by the network structure to a maximum of two radio hops for the network of 5 nodes and a maximum of 3 radio hops for the networks of 10 and 15 nodes.

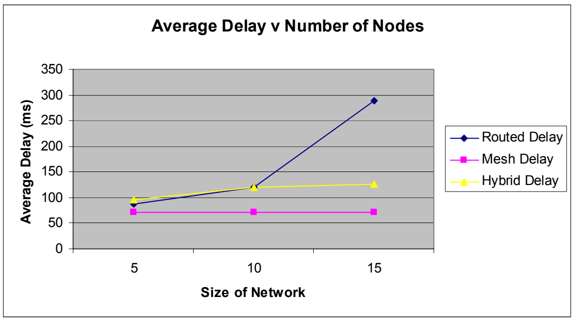

Figure 6: Average Delay – Different Network Types

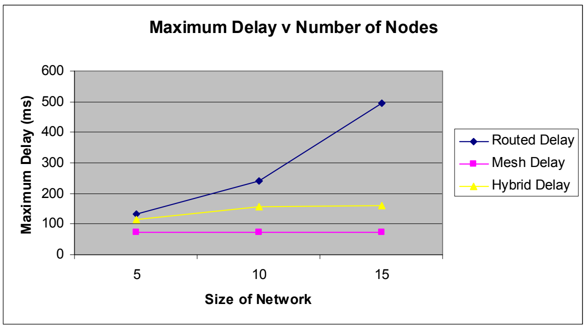

Figure 7: Maximum Delay – Different Network Types

In terms of radio link efficiency, Figure 8 shows the efficiency of each simulation as an average usage of all radio resources available. This is an average of the utilisation of all radio links. In this case the mesh network shows low utilisation (the same for all network sizes) as the data from one sensor is being sent on exactly one link.

The radio link efficiency for the routed network is a little misleading as in fact more traffic is carried in total through the routed network as the intelligent multicast feature is more effective in the hybrid network case. In the routed network many more copies of the same data are being carried on different links due to the lack of common routes in the various paths between sensor and receiver. This means that the routed network carries more traffic than the hybrid network (for the same size of network) but no more information. Thus the measure of efficiency shown here is artificially increased for the routed network.

For the routed network, efficiency increases with network size as the number of links per node (three in this case) is kept constant and more data flows are multiplexed on each radio link. Of course the problem of congestion is encountered at some stage when the net amount of bandwidth presented to some links (dependent on the routing algorithm used) exceeds available capacity.

Figure 9 shows the average radio resource, in terms of number or radio links per node, required against network size. The assumption here is that the broadcast capability in all networks is actually composed of a discrete number of directional antennas (one per destination). The advantage of the routed type network is clearly seen in that the radio resource remains constant with network size whereas it grows linearly per node (as a square law for the whole network) in the case of a meshed network.

The hybrid network shows the best use of resource as the number of links is reduced due to the hierarchical nature of the network.

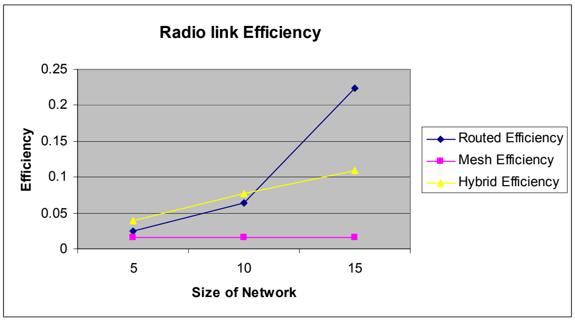

Figure 8: Radio Link Efficiency – Different Network Types

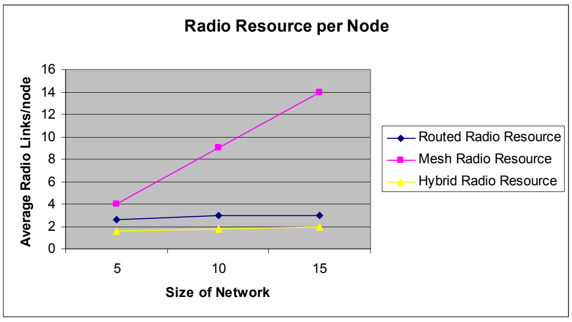

Figure 9: Radio Links per Node – Different Network Types

FUTURE NETTED SENSOR / NEC SUBNET ARCHITECTURES

Network Architectures

As there are both pros and cons for the routed and the fully meshed approaches, the logical deduction is that network topologies consisting of a combination of both approaches is a practical solution for future netted sensors and NEC subnet architecture. The hybrid network approach shows relatively modest increases in network delay as the size of the network grows with much better radio resource usage than the other two approaches. It also reduces the number of on-board routers required over the routed approach. However, the hybrid approach means that some platforms must be chosen as core nodes in any given deployment leading to some issues with configuring a network in any given scenario.

The recommendation is that the future netted sensor or NEC subnet architectures should be based on hybrid network multi-protocol-based architecture.

Radio Links Architectures & Technologies

In the past, military radio links have primarily been Serial-Input Serial-Output (SISO) systems. For these systems, multipath propagation is usually regarded as an impediment to high-speed data transmission which, if sufficiently large, results in frequency-selective fading, which in turn limits the maximum data rate that can be transmitted through the channel without introducing Inter-Symbol Interference (ISI).

There are three techniques in which a multiple antenna system can improve upon the throughput of a traditional Military-of-the-shelf (MOTS) radio links based on single antenna SISO systems:

- Beamforming;
- Receive and/or transmit diversity;
- Spatial multiplexing.

Therefore, the recommendation (to the designer) is that the future radio link architecture consists of combination of all three techniques. In this case, the FDD16 or Broadband Radio Access Links technology, based on IEEE 802.16 enhanced COTS technology [5, 6, 7 & 8], meets the requirements.

Phased Array Antenna

The future radio link technology will need to operate in two different modes: omni and directional. In the omni mode, each node is capable of receiving and transmitting signals in all directions (360 degrees) with gain G ≈ 2-3 dB. On the other hand, in the directional mode, a node can aim its high-gain antenna beam pattern towards a specific direction. In this case, the higher antenna gain means the range between nodes in directional mode can be much greater when compared with the omni mode range.

The design of a radio link phased array antenna for the future netted sensor / NEC subnet architectures may be readily achieved using PHASAR, developed and owned by Roke Manor, which is an advanced PHased Array Simulation for Adaptive Radar. EPSILON™, which is an advanced Radar Cross Section Prediction Tool, may also be used to support the design of radio link phased array antennas.

Satellite Range Extension

The Beyond Line Of Sight (BLOS) range and hence effectiveness of future netted sensors or NEC subnet architectures could be extended by thousands of square kilometres by using a dedicated military satellite data communications links. In this range extension technique, in order to ensure compatibility and interoperability with existing systems, the organisation of access to satellite communication bearers would be based on multiple access schemes.

Cost, Timescales & Performance Trade-Offs

The defence market requires constant innovation but, the military cannot take the same commercial and technical risks as industry. Therefore, the military need a good balance between a bespoke solution and COTS alternatives. All things considered, an optimised balance of functionality, flexibility and costs is needed for the future netted sensor or NEC subnet system.

CONCLUSIONS

The communications requirements and innovative technologies to enable the networking of sensors, at different levels of data sharing, in order to provide overall system performance advantages, has been studied and described.

The calculated future naval MFR sensor data bandwidth requirements for the identified levels of data sharing used are:

- Plot level – 60 Kbit/s;
- Detection level – 200 Kbit/s;
- Coherent level – 1.5 Gbit/s.

The LASSI Simulator, developed by Roke Manor, was used to investigate and evaluate the performance of the potential netted sensor or NEC subnet architectures. LASSI makes possible the study and design of network performance, including network delay and efficiency, for mobile and fixed networks communicating over a variety of radio link technologies.

The average delays for a homogeneous network of 10 future naval MFRs cooperating at the detection sharing level were: (a) routed: 240 ms, (b) mesh: 90 ms, (c) hybrid: 175 ms. Importantly, for the studied scenarios, the netted sensor system latency figures are comparable to the latencies associated with single sensors in the network.

The radio link efficiency for a network of 10 future MFRs co-operating at the detection sharing level were: (a) routed: 22.5%, (b) mesh: 2 %, (c) hybrid: 10%.

The average number of radio links per node for a network of 10 MFRs co-operating at detection sharing level were: (a) routed: 3, (b) mesh: 9, (c) hybrid: 2.

The study has shown that the optimum future radio link architecture consists of combination of three techniques: beamforming, receive and/or transmit diversity and spatial multiplexing. In this case, the novel FDD16 or Broadband Radio Access Links technology is suitable as a means of satisfying the requirements.

To summarise, the study has shown that the communications requirements of future netted sensors or NEC subnet can be fulfilled for the different levels of data sharing (track, plot and detection) using innovative hybrid networks and FDD16 broadband radio access links technology.

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