Chapter 8 – SUMMARY AND CONCLUSIONS

This report summarizes a four-year study carried out by NATO RTO/IST-030 Research Task Group 012 on the problem of "Information Management over Disadvantaged Grids". Such disadvantaged grids (e.g., tactical ad hoc networks) are characterized by low bandwidth, variable throughput, unreliable connectivity, and energy constraints imposed by the wireless communications grid that links the nodes. The Task Group studied managed information exchange from three different perspectives or levels within a system architecture: the application level, the middleware level and the network level.

The Task Group limited its scope to land-based data exchange on the tactical battlefield (i.e., below brigade level) where all nodes are mobile and the exchange medium is combat net radio. The objective of managed information exchange is to support the commander's ability to execute command and control by providing a timely flow of accurate, relevant information. At the tactical level, periodic updates of 'blue' situational awareness information (position of friendly units) every few minutes is the most important component of information exchange. Superimposed on this regular, periodic traffic is battle management traffic sent on an as-required situation-specific basis (e.g., report of enemy contact, patrol report, call for fire, or a fragmentary order).

Currently, there are two alternative approaches to tactical information exchange: data replication and formal messaging, both of which were addressed in this report. Of these options, data replication offers the most potential for minimizing bandwidth demands (by propagating data changes only, at the database transaction level), and for maximizing interoperability by exchanging data based on an agreed formal data schema. The Task Group focused primarily on this option. It was assumed that each mobile node exchanging data possessed a database that enforced a common data structure based on an agreed data schema, and that data exchange occurred by replicating database changes (transactions) on a local node to the databases on other network nodes using the shared radio medium.

The highly mobile tactical military environment creates several challenges not endemic to either strategic or civilian environments. The most crucial challenges include: low and varying data rate on a shared medium, unreliable links, and possibly severely limited resources such as energy or computational power as well as radio-silence situations. This report concludes that asynchronous replication mechanisms are best for this type of communications environment.

It is argued that an "all-informed" data distribution scheme offers several advantages in the disadvantaged, tactical domain. It takes maximum advantage of the shared radio medium, allows an easy hand-over of responsibility with minimum synchronization requirements, and avoids a single point of failure for important data. However, in the disadvantaged tactical communications environment, it will not be possible to maintain complete consistency of database content across all nodes in the network. Under these conditions, the replication mechanism needs to coordinate its efforts with the network to ensure the consistency of more important data at the cost of inconsistency of less important data.

The authors conclude that, with an appropriate addressing scheme, it is possible to combine an all-informed distribution model for certain types of information (e.g., position of friendly units) with a selective distribution model for other types of information (e.g., a fragmentary order). This hybrid distribution model, which combines full synchronization of database content for certain types of data with selective synchronization for other types of data, may provide the best match between operational requirements and bandwidth utilization in the tactical wireless domain.

Due to the highly variable quality of the tactical communications channels and the unpredictable nature of the tactical battlefield, it is argued that dynamic adaptation to rapid changes in either the communications or battlefield environment is required to achieve optimal information exchange. This adaptation is possible only if some information about the current status of the network is available to the middleware and/or application layer in each participating node.

Concerning middleware design, the report concludes that, in addition to the traditional requirements such as scalability, reliability and support for heterogeneity, next-generation middleware must meet several new requirements to satisfy the operating challenges in the tactical domain. The most important of these are context awareness, adaptivity, and the ability to function with acceptable levels of performance in both non-disadvantaged and disadvantaged communication environments. Another desirable quality for tactical middleware is an architecture that separates, to the extent possible, middleware services directly accessible to the application from the underlying connections to the communications network that support these services (so-called 'upperware' and 'lowerware'). Such an architecture eases the problem of adapting slowly evolving applications to more rapidly evolving communications technologies. It also permits applications to use the services of a single exchange mechanism that will exploit the best available transport mechanism based on context. The authors conclude that it is feasible to design middleware having all of the above characteristics, provided that both non-disadvantaged and disadvantaged environments are kept fully in mind from the outset.

This report has identified special characteristics of ad hoc wireless networks that differentiate them fundamentally from wired or cellular networks. The primary differences result from the lack of an infrastructure and from the fact that the set of network links and their capacities are not determined *a priori*. The tactical military domain imposes additional challenges such as low data rates, variable communications conditions and susceptibility to hostile environments. The report has discussed how designing tactical ad hoc wireless networks using cross-layer techniques rather than traditional layered design principles can provide performance benefits throughout the whole system, i.e., from the radio physical layer through the application layer.

Although this report recommends the use of cross-layer techniques, it discourages the complete abandonment of layers. It is felt that appropriate use of cross-layer techniques would respect the layered structure, but would optimize the network's overall performance in specific contexts by sharing selected information across layers. This approach would also facilitate sharing of key information about network state with higher layers (middleware and/or application).

The report has also discussed the difference between 'energy-efficient' and 'energy-constrained' operation. Both of these 'energy-aware' modes of operation are crucial to tactical networks involving dismounted soldiers because of the need to limit the weight of batteries that soldiers carry. Techniques that are based on minimization of total energy expenditure (summed over all network nodes) do not necessarily perform well when the batteries at the nodes cannot be replaced. Moreover, the total energy available to a node must be shared among the functions it must support. Energy-constrained operation leads to a strong coupling among functions at several layers of the protocol stack, and consequently is a strong candidate to benefit from the use of cross-layer network protocols.

Results have been presented from simulations driven by a tactical scenario in which exchange of position updates over a single tactical radio subnet is accomplished via data replication based on an all-informed distribution model. The results illustrate the positive impact that application-layer information management techniques that reduce payload size or limit offered load can have on information flow over disadvantaged tactical communication grids. In particular, the potential value of using context-sensitive information

management rules at the application layer to adjust the offered load to the network in response to network conditions without user intervention is demonstrated.

The authors' overall conclusion is that, for optimal information exchange performance in the tactical domain, systems need to be designed from a holistic perspective. All levels of a system architecture (application/ database, middleware and network) must be designed to work cooperatively to manage the information flow. This report has attempted to identify required attributes that must be present at each level to enable this cooperative behaviour.