# On the Performance of Intra-system Optimization of Virtual Manufacturing Communication Systems

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**Abstract.** New production environments will demand extensive exchange of communication information. Wireless communications will provide effective means to meet these demands. However, it is important that effective protocols are available to deliver the required QoS. Cross-layer algorithms are potential candidates that exhibit interesting features compared to monolithic traditional protocols. This paper analyses the performance of cross-layer enabled OLSR protocols compared to a hierarchical counterpart. The paper demonstrates that in the scenario defined cross-layer approach outperforms the intra-system optimization capabilities compared to a hierarchical OLSR enabled protocol.

**Keywords:** Cross-layer, OLSR, HLOSR, Virtual Manufacturing.

## 1 Introduction

The main objective is optimization to get efficient usage of the scarce radio resources. This will undoubtedly rely on cross-layer designs: Across-layer architecture encompasses an additional complexity relatively to a strictly-layered one, due to the fact that additional information besides the one that defines the basic service provided by the layer has to be exchanged. The need to exchange additional cross-layer information (CLI) leads to two fundamental questions:

- What information should be exchanged across protocol layers, and, how frequently should this exchange proceed?
- What are the adequate / efficient procedures to exchange this information?

This general question is currently being addressed by a large number of projects and authors. The benefits of cross-layer system design are mainly being applied in the area of mobile and wireless operators. In the recent years, the area of communications in the manufacturing is gaining importance. Traditional Ethernet and PROFIBUS factory systems are being enhanced to facilitate new means of automation. The role of wireless communication systems in terms of flexibility and self-configuration are attractive features that major manufacturers are trying to translate into business value to large companies.

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This paper is focused on the intra-system optimization scenario addressed by the European project LOOP. This project caters for the main data generation features related to future manufacturing environments and the communication needs and challenges. To this effect, the paper will initially discuss in Section 2 the concept of Virtual Part as a main source of production information. Next, section 3, will present the scenario and main challenges to be addressed by the communication environment. Then, the communication algorithms selected will be presented in Section 4 and the performance observed will be presented in Section 5. Finally, the main conclusions will be presented in Section 6.

## 2 Future Manufacturing Scenarios

As stated by Pat Byrne, president of Agilent Technologies' Electronic Measurements Group, the geographic diversification of manufacturing and R&D for many companies has created a challenge in maintaining quality and consistency. New products designed in one country may be prototyped in another and manufactured in yet another or even on another continent. The push to take advantage of the rich diversity of talent across the globe has increased our dependence upon robust measurement tools and techniques to ensure that the performance inherent in designs from the country of origin is maintained across the world at the end of the production line. Systems like the ones depicted in Fig. 1 do not fulfill the requirements set by such statements.

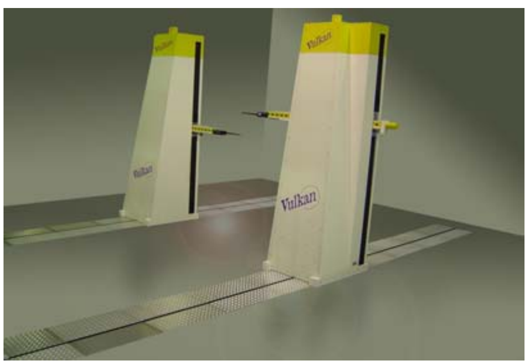


**Fig. 1.** Traditional Trimek Machine to Capture Dimensional Information of Manufactured Parts

To meet the challenges described above, it is necessary that a large amount of information is made available real-time, anywhere and anytime. The evolution, from a traditional system like the one depicted by Fig. 1, relies on the measurement of object dimensional features by extracting them from their corresponding Virtual Part (Fig. 2) and not from the physical object. A Virtual Part is 3D digital object that has a univocal relationship with its real counterpart, in terms of its dimensional, geometrical and surface characteristics. Hence, associated with the evolution of the manufacturing paradigm is associated the massive communication and management of information.

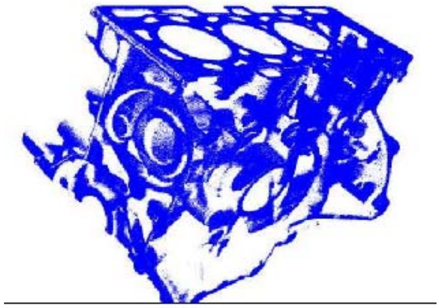

**Fig. 2.** Example of a Virtual Part

## 3 Communication Challenges

In order to identify the main communication challenges a scenario has been defined. The definition of a particular case is useful to specify the parameters of the scenario that we will simulate later. In our scenario we consider a car factory with two measurement areas in the same building with four production lines in each. The dimensions of these areas are 100x40m. Furthermore, in each production line there is a Trimek machine, which measures the pieces that are producing in the factory. Once a piece is measured, the machine sends its corresponding 3D Virtual Part to a virtual storage through a FTP connection.

All the information generated during the measurement process of the pieces must be stored in a virtual storage. Apart from the data, we will have to consider the transmission of video to carry out maintenance, calibration or repairing services in the production line

In the figure below we depict the defined use case, where each measurement area is equivalent to an ad-hoc network. There will be a Wi-Fi router in each ad-hoc network in order to have Internet access and it will work as cluster head in the hierarchical configuration. Hence, any component of one of the measurement areas will have the possibility to communicate with any component of the other measurement area.

In case the car factory opens a production plant in a different part of the plant or in a different country, an ad-hoc network connecting all the components of the new factory will be required. To that purpose the only device it should be configured it would be the wireless router. Once this wireless router has Internet access, the incorporated metrology gateways, nomadic workers and PCs would have connectivity with the rest of the components through Internet. Furthermore, these new components will be able to connect to Service of Technical Assistance (SAT) department of Trimek with guaranteed QoS.

The main challenges that the system will have to address are intermittent connectivity, extensibility, movement of users, and machines, high reliability, low cost and high throughput. For this reason an adhoc configuration has been selected for analysis.

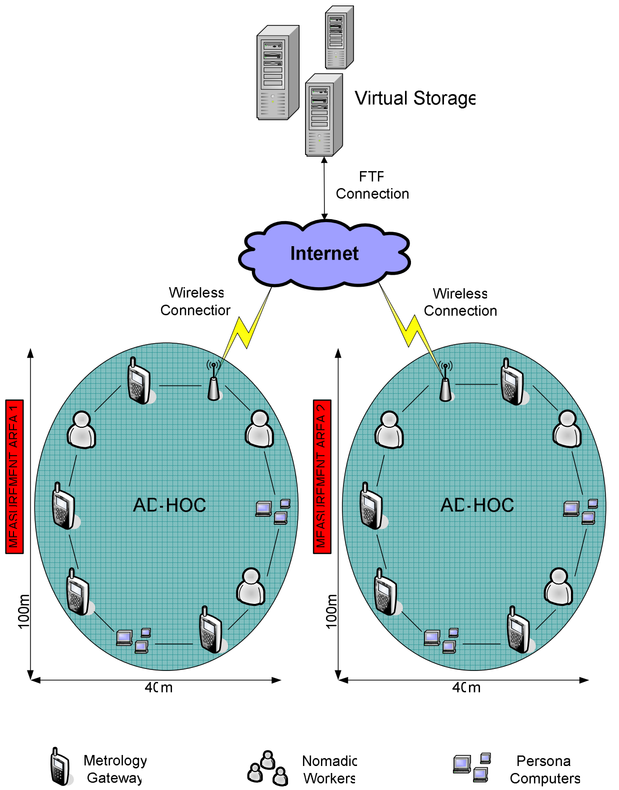


**Fig. 3.** Use Case Network Scheme

## 4 Intra-system Communication Optimisation

This section is devoted to analyze which are the most relevant aspects that can be derived in terms of network architecture and cross-layer protocol enhancements derived from the challenges presented in the previous Section.

### 4.1 Network Architecture

A network to serve the scenario above may be large in terms of both geographic expansion and the number of nodes. However, the penetration of the rate will vary along the deployment time and so would do the routing protocols selected for intra-system optimisation.

Therefore, a hierarchical architecture compared to a "flat" one, have been selected for investigation. The network hierarchy selected, as shown in Fig. 3, is based on a 2-tier hierarchy, which is a good tradeoff between network complexity and scalability.

As shown in the Fig. 3, the network is composed of a number of access networks connected through backbone nodes. The first tier is a backbone network composed of multi-hop connections with long distance wireless links connecting to several access networks. The backbone links are typically based on 802.11a links, and long distances between transmitters and receivers are achieved through directional antennas. The second tier is a mesh access network with short wireless links composed of a set of connected Mesh Routers (MRs) which serve as Access Points (APs) for end users. The connections between MR/APs and end users are typically based on 802.11b/g links. The backbone and access network itself is based on static topology however exhibits ad hoc features. In any case, the end users of this network can be either static (typically home users) or nomadic (typically visitors).

In brief, there are three categories of nodes in the proposed network architecture:

1. *Backbone nodes*: wireless devices used for backbone networks. Backbone nodes take part in routing.
2. *Mesh routers:* wireless devices used for mesh networking and serve as access points for end users. Mesh routers take part in routing.
3. *User equipments:* clients such as PCs, laptops, PDAs, wireless tablets etc. Users equipments are owned by either home users or visitors and do not take part in routing.

### 4.2 Network Characteristics

Inherited from ad hoc routing protocols, the routing strategies in Wireless Mesh Networks (WMNs) can also be classified as reactive, proactive or a hybrid of them. Although reactive protocols generate less overhead in general, they cannot provide instantaneous node and link status information since no messages are exchanged among mesh routers if there is no data traffic. This means that reactive routing protocols cannot provide real-time network availability information to system administrator, which is crucial from reliable service provisioning point of view. Therefore, the most representative proactive ad hoc routing protocol, Optimised Link State Routing (OLSR), has been selected as the baseline protocol for developing our routing strategy in LOOP networks.

Another reason for selecting OLSR is because of its legacy inter-network connection capability using Host and Node Association (HNA) messages. With this message, a gateway node is able to advertise its Internet *reachability* to all other nodes, so that they can access the Internet through the gateway. It is worth mentioning there that even though Radio-Aware OLSR has not been included in the newest version of the IEEE 802.11s mesh networking standard [1], the function of HNA has been integrated as part of their hybrid routing protocol.

However, the hop-count based OLSR specified in [2] is not able to fulfill the requirements for our targeted network. Therefore, a number of enhancements to the legacy OLSR protocol have been designed within the project, as presented in the following subsections.

### 4.3 OLSR Enhancement: Hierarchical Structure

There are two levels of hierarchy according to our network design where Level-1 hierarchy corresponds to connection among backbone network nodes, while Level-2 hierarchy corresponds to connection among mesh routers in access networks. An access sub-network which is connected to other access sub-networks is referred to as a cluster. A backbone node serves as the cluster head and advertises its reachability to other clusters periodically. The cluster heads are predefined, thus there is no need to develop an algorithm for cluster head selection. Each cluster-head uses HNA to advertise its reachability for both sides:

- **Inter-cluster.** HNA message advertises a cluster-head's connectivity of all nodes, including both mesh routers and Internet gateway nodes inside the same cluster, to other clusters. This message is sent to all other connected cluster heads using unicast packets (note this is different from the standard version of OLSR), or subnet-directed-broadcast packets. Both the mesh router and the gateways are advertised as connected subnets, specified by the netmask field in HNA.
- **Intra-cluster.** HNA message advertises a cluster-head's connectivity to other clusters, including also Internet gateways from another cluster. This message is sent to all mesh routers inside the same cluster. Both mesh routers and gateways from another cluster are advertised as connected subnets, and are specified by the netmask field in HNA.
- For both inter-cluster and intra-cluster HNA messages, an extended HNA format has been used, so that metric-based routing can be used for gateway selection of any mesh router. Various metrics, for instance, the airtime metric, can be used in our implementation [3]. Moreover, every mesh router in a cluster is advertised as a special type of "gateway", in which it acts as an AP for its clients, and therefore it generates HNA messages as well. The cluster-head, upon receiving this information, establishes an HNA Information Base, which is then used for building the inter-cluster HNA messages to be forwarded to other cluster heads.

### 4.4 OLSR Enhancement: Multi-homing with Load Balancing

HNA messages in OLSR allow gateway nodes to announce their network association (network address and netmask) with the Internet to other OLSR nodes. When multi-homed, the gateway which is closest to the end-user, in terms of the number of hops, is always chosen as the default gateway by the legacy OLSR. The other gateway will be used only if the default gateway is down, and the process of finding another gateway may take up to a few seconds.

With the implemented multi-homing enhancement, a node uses a metric-based policy to select the best gateway. These metrics include for example link and path capacity, traffic load and other QoS parameters, in addition to the number of hops.

Three types of load balancing have been considered in our network, namely load balancing among channels, paths and gateway nodes. Given that two or more channels co-exist between a pair of nodes, if one channel is close to congestion, another channel should be used. Similarly, if one path is over-loaded, the routing table calculation process will re-calculate a new path. This is triggered by including the traffic load information in a newly defined "LINKINFO" message, which has been implemented as a plug-in to OLSR.

### 4.5 OLSR Enhancement: Cross Layer Link Layer Notification

When a link break happens, the legacy OLSR will react to this change by exchanging "HELLO" and "TC" messages and this process may take up to a few seconds. With link layer notification, a new path, if existing, will be available immediately (e.g. in the order of milliseconds) after a link break. With this enhancement, we are able to provide the end-users with non-interrupted access.

The basis for this enhancement is to utilize link break information gathered at the MAC layer to impose OLSR routing table re-calculation. More specifically, the MAC layer detects the link break and sends an indication to the protocol layer. Upon receiving such an indication which is treated as a topology or neighbour change, OLSR shall conduct routing table re-calculation immediately.

## 5 Performance Evaluation

The first analysis carried out on the proposed enhancements is directed to understand which protocols are more effective in a factory configuration. In the scenario analysed we have only considered a single warehouse. The ns-2 simulator has been used.

The simulated scenario considers a 4000 square meter area representing the production lines. Each production line generates a fixed amount of data based on the pieces of work being measured – see Fig. 1. The pieces measured will vary in data size based on the digital information gathered. To our analysis we have considered such data sources as being Constant Bit Rate (CBR), since data will be produced at regular intervals – piece production interval – and the data provided will be always of the same size. Thus, a CBR source with varying bit rate is created and this background traffic is transmitted via ftp. The size of a cloud of points used in the simulation will be 200Mb more or less, and Trimek machines will digitalize a car door in 20ms. Thus, we will need a connection of 10Mbps for data. On the other hand, we must also consider the video of 2'8Mb that will be transmitted in each simulation.

The objective of the scenario is to evaluate the performance of a multimedia service that is carried out on top of this network. This service would permit that timely data for process configuration can be served on real-time. This information is used by production engineers to complement the information received in the form of virtual part.

The network is composed 20 nodes operating in the network. 6 nodes represent nomadic workers. 6 nodes are fixed terminals and the remaining 8 nodes are metrology gateways – routers. In the hierarchical case the nodes are evenly distributed in each cluster.

In the scenario considered, we are mostly interested to analyse the performance of both flat and hierarchical enhancements described in the previous Section. It is of great importance to understand which approach is more effective, namely cross-layer or hierarchical to deploy the correct solution based on the dimension addressed.

The objective of the analysis was to observe the performance of video communication over the network as the transmission of the virtual part was taking place. Such multimedia stream would be directed to experts in assisting the manufacturing decisions all over the plants that are normally very large. The video connection has a bit rate of 128 kbps and a QCIF format.

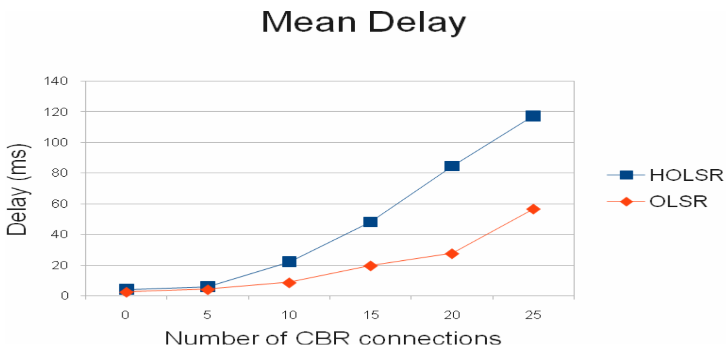


**Fig. 4.** Average Delay - Hierarchical OLSR vs enhanced-OLSR

To ensure the accuracy of the results 7 independent simulations have been carried out so that a confidence interval smaller than 1% of the results depicted is attained.

First we analyze, the performance of HLOSR and OLSR with increasing number of connections

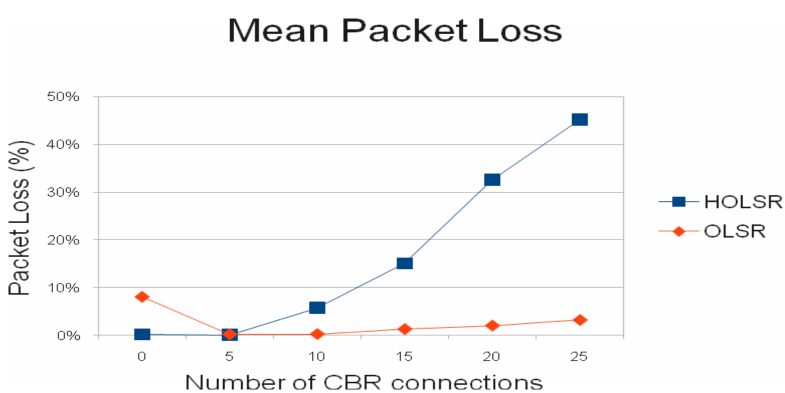


**Fig. 5.** Average Packet Loss - Hierarchical OLSR vs enhanced-OLSR

As it can be observed, from Fig. 4 and Fig. 5 the performance limiting factor is the Packet Loss. With the packet loss of 5% we can achieve a suitable Peak Signal to Noise Ratio (PSNR) on the video connections. Taking this value as reference we can conclude that a maximum number of 7 connections can be obtained with the hierarchical enhancement compared to the 25 supported with the cross-layer supported OLSR enhancement. This performance can be attributed to the fact that the scenario considered is relatively small in coverage area, so flat structures with a cross-layer support are more effective than hierarchical counterparts. This is related mainly to inter-cluster signaling and overheads created at the cluster heads, which do not prove effective over small areas.

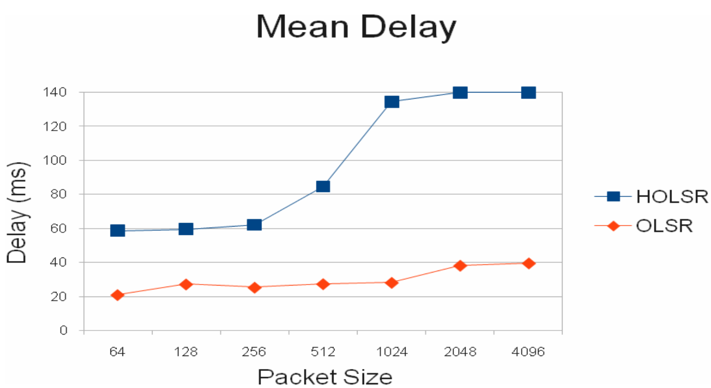


**Fig. 6.** Average Delay - Hierarchical OLSR vs. enhanced-OLSR

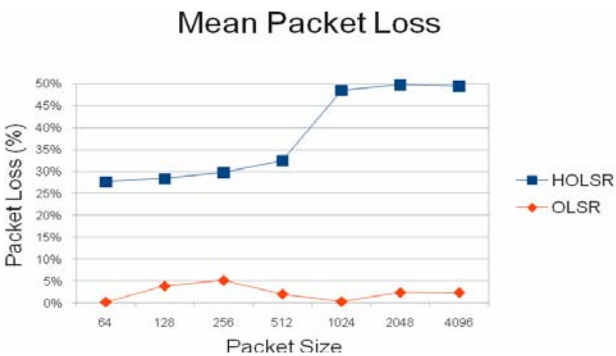


**Fig. 7.** Average Packet Loss - Hierarchical OLSR vs. enhanced-OLSR

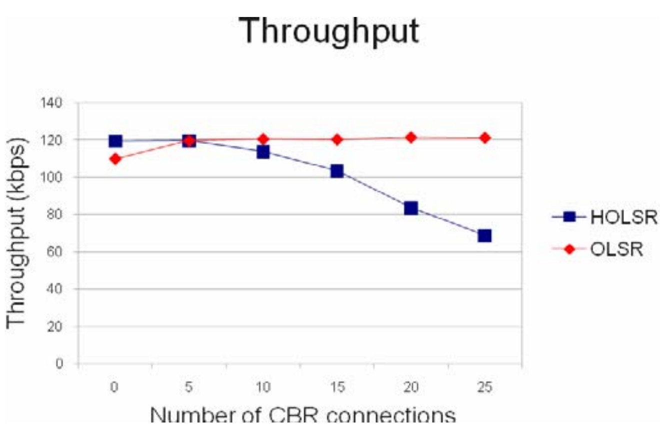


**Fig. 8.** Throughput - Hierarchical OLSR vs. enhanced-OLSR

The second analysis is carried out in terms of the packet size employed for transmission.

In terms of the packet size employed (Fig. 7), the performance is also very similar between both algorithms and the previous observations in terms of performance and intra-cluster heavy load traffic are reinforced.

To conclude the previous discussion, Fig. 8 shows that the average throughput obtained in the OLSR case is more favorable compared to the Hierarchical OLSR (HLOSR) one.

## 6 Performance Evaluation

This paper has presented the challenges posed by the future manufacturing scenarios and how cross-layer design could help to meet such demands. Two different strategies, namely cross-layer OLSR and HOLSR have been proposed to face the communication needs of such scenarios. To evaluate the performance of such algorithms a user scenario has been defined and the algorithms simulated. The results obtained suggest that due to the smaller area over which the communication network is deployed, intra-system optimization based on cross-layer approaches is more effective than the hierarchical counterparts.

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