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## DELIVERABLE INTRODUCTION

Deliverable 6.3 is titled “Preliminary report on optimized fleet management to reduce energy consumption and costs “. Its objectives are:

- a) to investigate the potential savings in energy consumption and production cost by optimising single and multiple machine (fleet) machine usage at the farm level
- b) to investigate the required data, information flow and information management for optimised farm mechanization management comprising single machines or fleets of conventional, or autonomous machines.

The deliverable consists of three reports.

### Report 1:

This report presents a scientific literature review to assess what the research community has shown to be possible for planning and managing the operation of teams of conventional and semi-autonomous machines. Then, it presents the currently available commercial technology for planning and managing the operation of agricultural machine fleets. It proceeds by identifying the limitations of currently available commercial research-prototype systems. Finally it offers recommendations for bridging the gaps between what is commercially available, and what constitutes state of the art in research, and develops a roadmap for what needs to be developed further.

### Report 2:

This report presents an assessment of the energy and cost savings that could be achieved when farming operations (e.g., fertilising, grain harvesting) are performed by many machines (fleet) operated in an optimal way, as opposed to the standard operation of current agricultural practice. The assessment will be based on available state of the art algorithms which model, optimise and simulate the execution of agricultural operations at the farm level.

### Report 3:

This report investigates the required data, information flow and information management for optimised farm mechanization management comprising single machines or fleets of (autonomous) machines. It compares the currently available data flow with the required one, identifies the limitations of current technology and suggests directions for future technological development.

# Fleet Management: Data and Information Requirements

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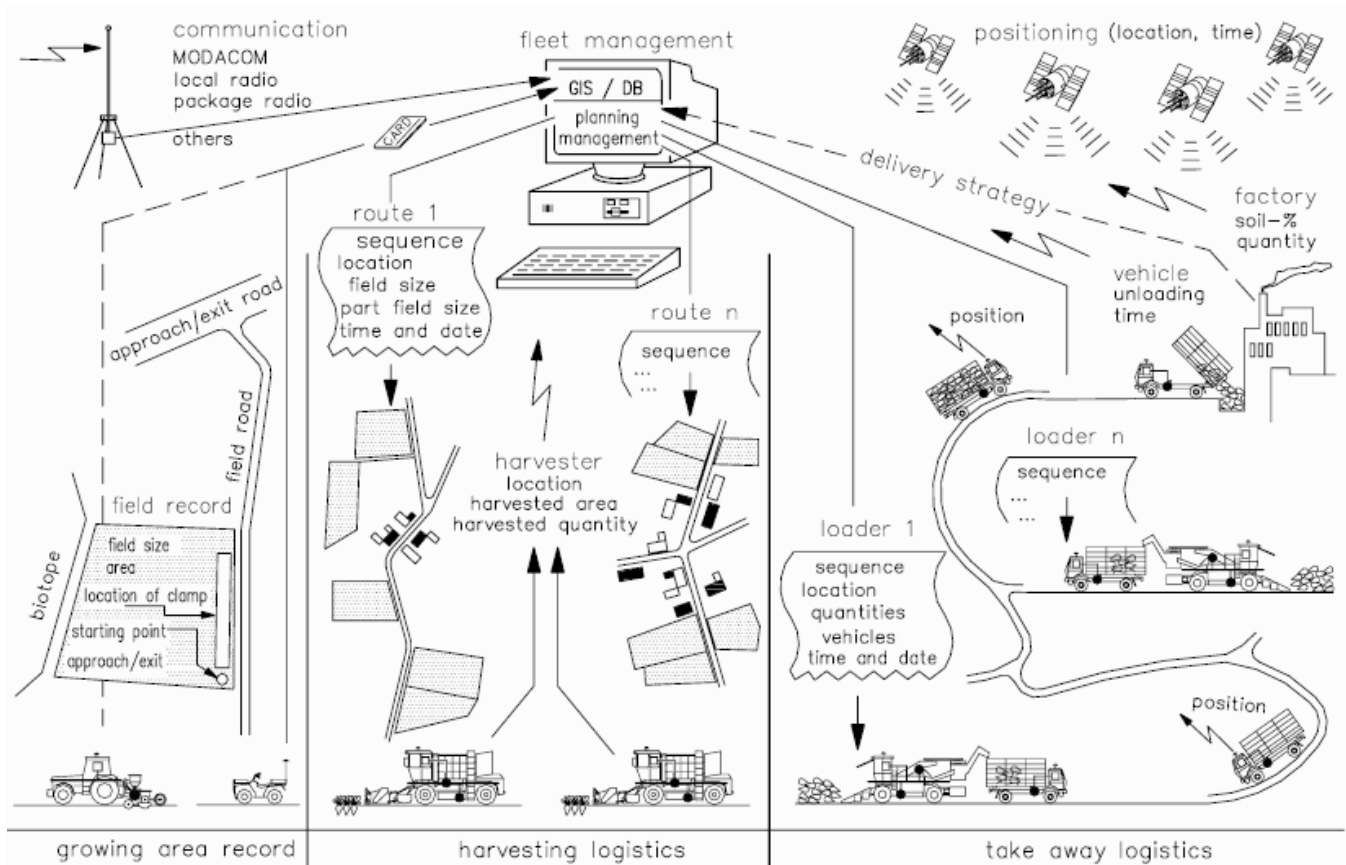
This section of the report analyses the data and information requirements and flows of a fleet management system aimed for agricultural operations. The term “data” refers to numbers or strings that can be stored in a database, communicated over some network and that can be used by some algorithm in order to come up with optimal or near-optimal solutions to current scheduling and in-field operation problems. The term “information” is contextualised data and refers to any input can be used by humans to alter or guide the solution computed automatically by the system. One way to achieve this is by adjusting the cost function or the constraint set of the problem. For example, the current locations of all combine harvesters of a certain type in a fleet constitute data. The fact that the operators’ union has declared a strike for the next day constitutes information that must be entered into the system so that re-scheduling can be done. The flows of data and information describe the paths that these entities may travel from the point of origination to destinations, and back and the precedence relations that may exist.

## 1 Data and information flows

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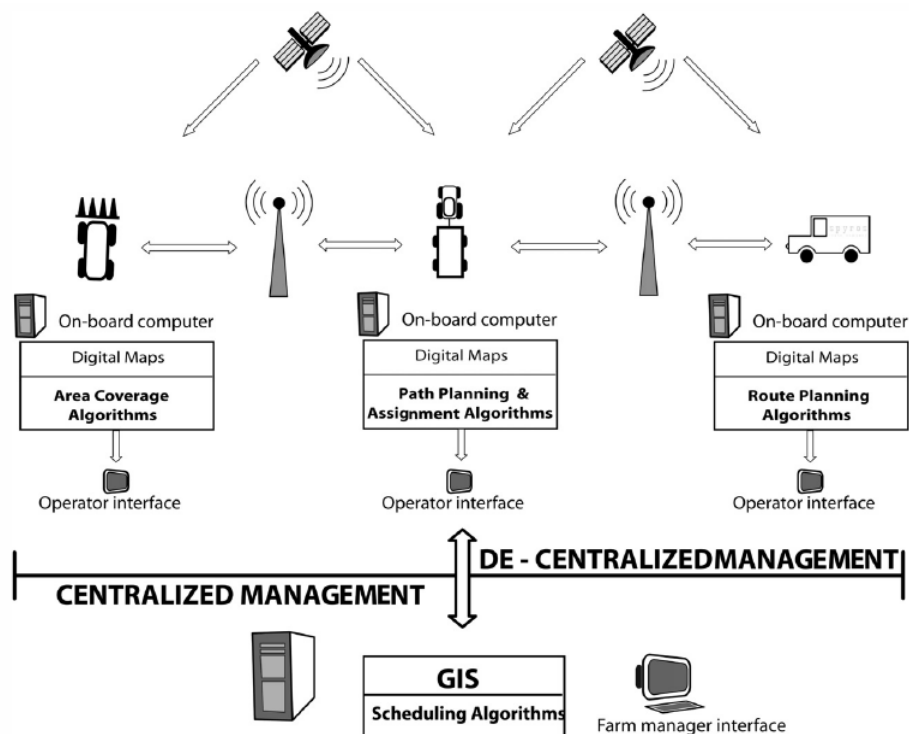
Fleet management systems must operate at different levels of abstraction and different time scales if they are to become practical tools for farm machinery management. Off-line (static) scheduling algorithms require a-priory knowledge of all problem parameters and accurate predictions of the durations of in-field operations and inter-field transfers in order to be able to compute reliable schedules. Their computational complexity is very high and it may take tens of *minutes*, or *hours* to come up with close-to-optimal schedules. The computation depends on the size of the problem (number of fields, operations, types of machines, other constraints). As a general notion, off-line planning algorithms require *global knowledge* about the fleet and the field operation requirements and can execute only on powerful computers. Therefore, it makes sense to run them on a *central* computing system as a part of a central administrative system, also called the *dispatcher*. Similar claims can be made for off-line traffic planning for operations in the field, where knowledge of all vehicle states and field conditions are required. However, the computational effort may be significantly lower, depending on the pursued approach. For example, field coverage with small rectangular cells (Ali et al.,

2009) requires two orders of magnitude longer computation (hrs) than parallel swath-based coverage (Oksanen, 2007) (min). In a centralised scheme, scheduling and traffic planning can be optimised together resulting in an improved performance. An example of a centralised system is the PROGIS LoGistic system currently being used by the German sugar beet producers and machine contractors. All scheduling is performed on a central dispatching computer which has access to a GIS and database of all data relevant to the harvesting of all fields. In this system, no traffic planning is performed, since the machines are conventional and do not utilise auto-guidance.



**Figure 1** Centralised architecture for management of conventional machine fleet for harvesting (PROGIS LoGistic)

If the simpler approach were used, in-field traffic planning could be performed locally by the on-board computer of a designated coordinator machine, or centrally by the dispatcher. The scenario where scheduling is performed centrally and traffic planning is done locally is proposed in the work of Sørensen and Bochtis (2009). One drawback of this scenario is that scheduling and traffic planning are decoupled and there is no way that they could be optimised together, if more computing power were to become available. A centralised scheme would keep such an option open.



**Figure 2** De-centralized vs. centralized planning distribution (Sørensen and Bochtis, 2009).

Once each machine has received its scheduling and field traffic plan from the central computer, the traffic plan's coordinated execution in the field requires *real-time* control and high-bandwidth, low-latency communication among members of the coalition operating in the field. Naturally, these algorithms must execute *locally*, using the on-board navigation computers of the machines. It would be technically impossible for a central computer to control the navigation and operations of all machines.

During a number of cultivation operations it is very likely that the traffic plan will need to be recomputed due to unexpected events or conditions in the field. For example, differences between the real crop yield distribution and its off-line prediction may render the planned grain unloading places and times obsolete, causing the a-priori traffic plan of the loading carts to become useless. The on-line computation of a new plan or the modification of the existing one requires information from all machines involved in the cultivation of the particular field and must be computed very fast to avoid idle times. Of course, a new traffic plan may influence the overall performance or feasibility of the original schedule. The ideal solution would be to re-solve on-line the entire scheduling and traffic planning problem centrally every time some parameter changes. This is – and most likely will remain – impossible because of the problem's computational complexity. One approach is to decouple the scheduling from the traffic planning problem so that effectively the dispatcher *abstracts* the detailed in-field traffic patterns and treats them as simple numbers expressing the duration of in-field operations for any given machine assignment like traditional capacity planning (e.g. Sørensen & Nielsen, 2005). This means that the new in-field traffic plan could be computed locally and that only the updated estimated cultivation time must be communicated to the central dispatcher. The new plan could also be computed centrally and sent back to the coalition. In terms of speed, the choice will depend on the ratio of central over local CPU power and on the communication delays. In terms of reliability, it would be preferable to perform computation locally to avoid possible dispatcher or

communication failures. Both schemes can be implemented in a more coordinated and timely fashion if one machine acts as a team coordinator, responsible for communicating with the central dispatcher and for re-computing plans (Johnson et al., 2009). For example, if a new field traffic plan has been generated by the central computer each machine of a coalition must receive the entire plan, or the part that is relevant to itself. However, before switching to executing the new plan, it should be made sure that all machines have received it. If communication is between every machine and the dispatcher, this will require additional messaging among the members of the team. If a local coordinator exists, it is much easier for this coordinator to distribute the updated plan to all involved parties and verify its reception before signalling its initiation. Of course, if the coordinator fails for some reason, another machine could take its role using some well defined protocol.

One very important issue related to data and information flow is the issue of representation. A fleet management system should be able to communicate with on-board computers of agricultural vehicles of different brands and vice versa, i.e., a vehicle of one brand should be able to exchange data with fleet management systems of different brands. As part of fleet management development efforts, improvements in the on-machinery communication interfaces and connection to the central managing unit are important. On-going work in this area include the ISO TC 23/SC 19/WG1 (Agricultural Electronics) standard, which has the purpose of setting up an open interconnected on-board system, permitting electronic units to communicate, and to define the data exchange with the Farm Management Information System (includes software, decision support system, etc. for farm management).

## **2 Data and information requirements**

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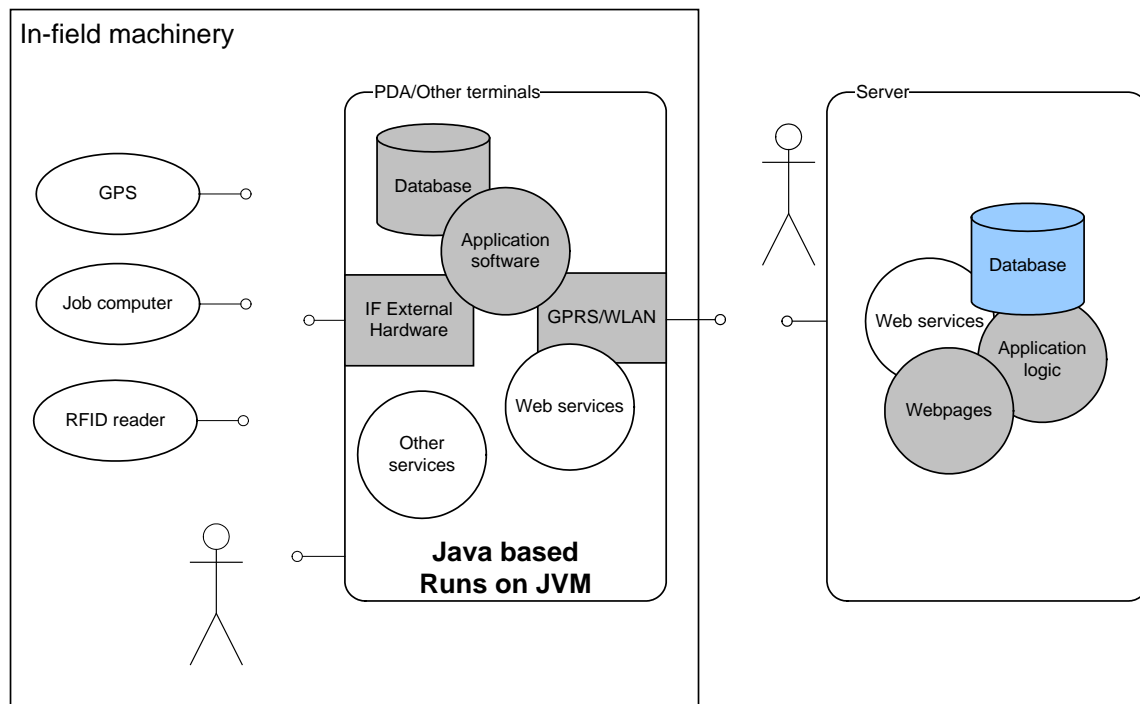
As a first step, the data required for assigning and scheduling machines to field operations as well as for planning their in-field traffic pattern off-line is considered. These procedures do not require any real-time data, since it takes place prior to execution of the operations. An indicative list of required data is given below:

1. the set of the fields to be serviced located on a suitable detailed GIS map, from which the field boundary, field and headland areas and any obstacles can be computed accurately, along with additional descriptive data, such as ownership, soil condition, etc.
2. the set of operations to be performed in each farm in a suitable representation. For example: for a harvesting operation, the expected yield distribution together with additional descriptive data (crop type, predicted price, earliest and latest harvest dates, yield loss function due to non optimal harvest date, timeliness function, etc)
3. the sequence in which the operations must be performed in each farm
4. the distance from one farm to another farm. This can be estimated by searching the road network available in the GIS.
5. the time required to transport any machines from one farm to another farm estimated by using distance and expected transport speeds.
6. the price of fuel

7. the set of machines in the fleet. This set gives the composition of the fleet, and contains for each machine, its type and suitability for each operation, its availability, operational characteristics, like operating width, turning radius, fuel tank capacity, material capacity (where applicable), fuel consumption, operating costs, etc. The number of machine types, the number of individual machines of each type and similar data can be extracted from this set.
8. the set of crew members (operators, assistants) and data related to them like hourly costs, availability ability to operate or service different types of machines, etc.
9. the initial locations of all machines
10. the minimum and maximum time lag between successive operations at each farm
11. the set up time of machines of a given type and the crew requirements
12. the time needed to carry out each operation at each farm if a certain number of machines of a specific type are used
13. historical weather and prediction data that can be used to assess soil conditions, predict unavailable days due to high probability of rain, etc.

**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** outlines the principles of automated data acquisition as part of a fleet management system. It includes data capture on in-field machinery and data transfer to a server accessible via the Internet. An additional functionality is “context awareness”. Context awareness is a term that is used for devices that have information about the circumstances under which they operate and can react accordingly. Context aware devices may also try to make assumptions about the user's current situation. For example: A context aware fleet management system may know that one of the mobile units is currently approaching the storage facility. The system may then display information to the operator needed for the unloading procedure.

### Context awareness



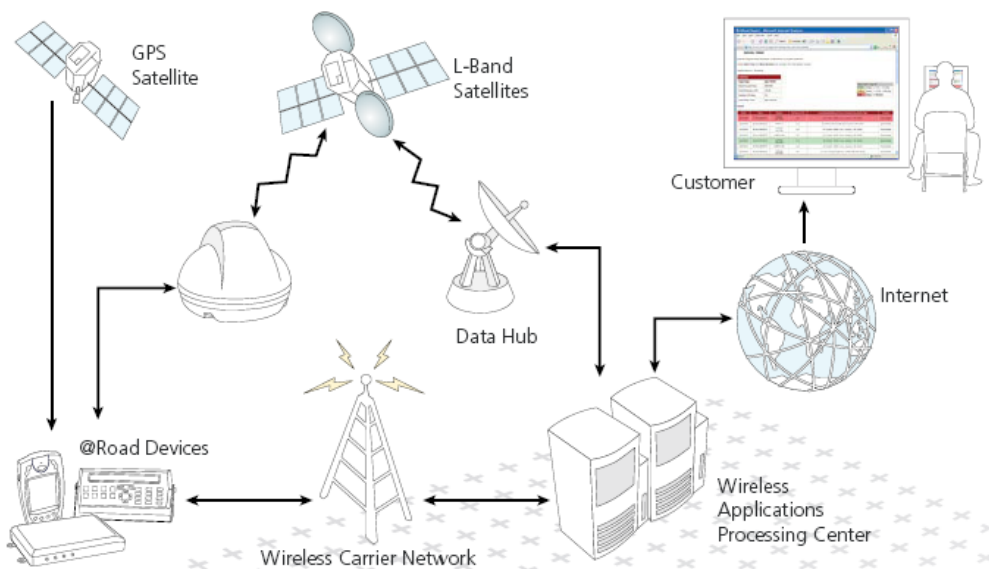
**Figure 3** Automated data acquisition as part of fleet management

### 3 Communications infrastructure

Within a fleet management system data and information needs to be exchanged between the central dispatching station and the vehicles, and between vehicles. The purposes and requirements of each type of communication are different and will be examined next.

#### 3.1 Dispatcher-to-vehicle

Communication between a vehicle and the central dispatching unit is typically long distance with ranges that may exceed hundreds of kilometres. Each vehicle must send periodically, preferably in real-time its position and operational status to the dispatcher. This is already achieved by commercial fleet management systems using established commercial satellite and cellular telecommunication technologies. In Europe, where the coverage of GSM networks is very high, the need for satellite communication is lower. In contrast, such communication in USA, Canada, or Australia may need to rely on more expensive satellite links. Combinations of both technologies are also possible (Figure 4). The 2G GSM system supports data communications at the maximum rate of 9.6kbps. Higher data rates are possible when GPRS (<171kbps) and EDGE (<384kbps) are available. New 3G systems support much higher maximum data rates of 144kbps and 384kbps under high mobility and low mobility.

**Figure 4** State of the art fleet management communications architecture (Trimble's @Road GeoManagerSM iLM® solution)

### **3.2 Vehicle-to-vehicle**

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Once each machine has received its scheduling and possibly its field traffic plan from the central dispatcher, the on-board tracking controllers of the vehicles in the coalition will have to execute all or part of the traffic plan autonomously in a coordinated manner; hence fast and reliable communication mechanisms will be required. The two main operations which put a heavy burden on communications are cooperative motion control and collaborative collision avoidance. Although algorithms exist which rely solely on local sensing for coordination and collision avoidance it is expected that coordinated motion and collision avoidance in agricultural applications will use the services of the high precision GPS units available on most modern vehicles. This means that at minimum the tracking controllers of each vehicle involved in a formation will have to broadcast or unicast the vehicle's state (position, velocity, acceleration, fuel and material tank level, etc) to all other vehicles in the formation, or, in a general sense, to nearby vehicles. If more elaborate coordination algorithms are used, such as predictive control, then the future states within a short time horizon must be sent.

The key characteristics for evaluating wireless technologies for vehicular network communication are: performance, coverage area, reliability, security, and mobility. Performance is assessed from measured bandwidth and latency. High-bandwidth and low latency are necessary to maintain fast and timely data exchange suitable for real-time coordination. Coverage area is evaluated from the measured distance needed between base stations, the number of devices required to support the infrastructure, and whether the technology has the ability to switch/hand-off between base stations without loss of coverage. Coverage area is an important characteristic for in-field coordination because fields can be quite large, in the order of hundreds or thousands of meters. Reliability is characterized by the average number of dropped packets, average number of disconnects, and whether the technology is affected by environmental factors such as line of sight, weather, etc. Reliability is very important because the network will be used for coordinated motion and collaborative collision avoidance requiring constant communication. If a connection is not reliable, packets are being dropped and the speed of the network connection will decrease. This would adversely affect the performance of the operation. Mobility is the speed of the mobile access point at which the technology can connect and remain connected without packet loss or service interruption. Naturally, a wireless vehicular environment will need to be mobile. The network must sustain connection at vehicular speeds which in agricultural applications are not very high.

Since digital tracking controllers operate with a sampling period of a few milliseconds, coordinated motion and collaborative collision avoidance will require *high-bandwidth, low-latency, high reliability, relatively long range* and *relatively high mobility* networking technologies among members of the coalition operating in the field. In the next paragraphs existing candidate wireless technologies will be presented and compared. These technologies are: DSRC (IEEE 802.11p), WiMAX (IEEE 802.16) and 3G (ITU). A future emerging standard, MBWA (IEEE 802.20) is also presented.

Dedicated Short-Range Communication (DSRC) is a short to medium range communication technology operating in the 5.9 GHz range, which was developed especially for vehicle-to-vehicle (V2V) network applications (ASTM E2213-03, 2003). DSRC systems in Europe, Japan and U.S. are not at the present moment compatible. In the US DSRC will be based upon a group of IEEE standards, namely IEEE 802.11p and 1609 family, and will use seven 10 MHz-wide channels in the 5.85-5.925 GHz bandwidth.

IEEE 802.11p is an extension to 802.11 Wireless LAN medium access layer (MAC) and physical layer (PHY) specification in order to add wireless access in the vehicular environment (WAVE). WAVE mode of operation foresees data exchange between vehicular devices in rapidly changing communication environments, where mobile stations may move up to *200 Km/h*, have a nominal transmission range of *300m* (up to 1000m), and default data rate of *6Mbps* (up to 27Mbps). DSRC has two modes of operations: (1) Ad hoc mode characterized by distributed multi-hop networking (vehicle-vehicle), (2) Infrastructure mode characterized by a centralised mobile single hop network (vehicle-gateway). Depending on the deployment scenarios, gateways can be connected to one another or to the Internet, and they can be equipped with computing and storage devices. The communication between the V2V devices is performed through a pre-assigned communication channel when nearby vehicles are within range. It takes approximately 20 ms to handshake. Then each vehicle would allocate a channel, out of 10 possible channels, and communication would take place through that dedicated channel. The minimum time for data exchange between two vehicles is in milliseconds. This time includes data transmission and broadcasting latency and would vary depending on the load on the communications channels. A recent study has shown that the delay performance of a DSRC warning message falls well within the 100 msec delay requirement for safety applications (Tang and Yip, 2010). On the other hand the average throughput lied between 50% and 60%, which is considered modest performance from a safety point of view since more than 40% of vehicles, on the average, within the sender's broadcast range will not receive the warning messages.

WiMAX is the latest wireless technology to be approved by the IEEE 802.16 working group. It is a standard for point-to-multipoint wireless networking. The IEEE 802.16e version is an extension of the IEEE 802.16 standard that was drafted specifically to deal with mobility. WiMAX is a point-to-multipoint (PMP) technology that operates in the 10 to 66GHz and sub11GHz wavelengths. At higher frequencies, line of sight is a requirement. It can provide service over distances up to 50 Km. The WiMAX-based solutions are set up and deployed like cellular systems using base stations that service a radius of several kilometres. The most typical WiMAX-based architecture includes a base station mounted on a building and shall be responsible for communicating on a point to multi-point basis with subscriber stations located in business offices, homes, and automobiles.

Cellular systems have been evolving rapidly to support the ever increasing demands of mobile networking. The 2G GSM system supports data communications at the maximum rate of 9.6kbps. To provide higher rate data communications, GSM-based systems use GPRS (<171kbps) and EDGE (<384kbps). Now 3G systems support much higher data rate. UMTS/HSDPA provides maximum rates of 144kbps, 384kbps, and 2Mbps under high mobility, low mobility, and stationary environments respectively. The average data rate perceived by users is much lower in practice: <128kbps for GSM/EDGE and <512kbps for 3G technologies. The reported packet latency is 150-250ms. The behaviour of 3G services in a vehicular environment has been evaluated by Qureshi et al. (2006). They reported that 1) the average round trip time (RTT) was consistently high (around 600ms) with a high variance ( $\rho=350ms$ ); 2) there were a small number of short-lived (<30s) disconnections during their experiments; 3) the download throughput varied, ranging from 100kbps to 420kbps, and the peak upload throughput was less than 140kbps; and 4) they found no correlation between the vehicle's speed and the achieved throughput, but geographic location is the dominant factor leading to variations. The high latency of the GSM packets and the variance in round trip times make even UMTS/HSDPA technologies, a poor choice for vehicular coordination.

Another candidate technology for V2V applications is Mobile broadband wireless access (MBWA) which is a name given to the IEEE 802.20 standard currently under development. The standard is still in its infancy and it is hoping to standardize an efficient packet-based air interface that is optimized for the transport of IP-based services. The goal of this standard is to enable worldwide deployment of affordable, ubiquitous, always-on and interoperable multi-vendor mobile broadband wireless access networks. The goal is also to support vehicular mobility up to 200 Km/h with spectral efficiency (throughput/bandwidth). It seeks to boost real-time data transmission rates in wireless MANs (metropolitan area networks) to speeds that rival DSL and cable connections. It is being designed to operating in small chunks of spectrum, meaning that the required channel bandwidth is small. It requires base stations and has an approximate base station range of 15 Km. Summarising, the following table presents a brief comparison of the wireless technologies.

**Table 1** Comparison of wireless technologies

	Max. Bit rate	Latency (expected)	Range (up to)	Mobility (up to)
DSRC (IEEE 802.11p)	54 Mbps	50 ms	300 m	160 Km/h
WiMax (IEEE 802.16e)	100 Mbps	25-40 ms	50 Km (LoS) 8Km (NLoS)	120-150 Km/h
3G	2 Mbps	500 ms	1.5-8 Km	120 Km/h at 384 Kbps 10 Km/h at 2 Mbps
MBWA IEEE (802.20)	16 Mbps	10-30 ms	15 Km	250 Km/h

Safe navigation support through wireless car-to-car and car-to-curb communications has become an important priority for car manufacturers as well as transportation authorities and communications standards organizations. While safe navigation has always been the prime motivation behind vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, vehicular networks provide a promising platform for a much broader range of large scale, highly mobile applications. Given the automobile's role as a critical component in peoples' lives, embedding software-based intelligence into cars has the potential to drastically improve the user's quality of life. This, along with significant market demand for more reliability, safety and entertainment value in automobiles, has resulted in significant commercial development and support of vehicular networks and applications. Therefore, the driving force behind V2V technologies is the car manufacturing industry. Given the strict safety requirements from V2V technologies the most promising existing technologies are DSRC and WiMax, provided that a worldwide standard will be achieved. MBWA promises to be superior to both of them, but it has not been implemented yet.

## 4 Conclusions

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On-line fleet management must operate at the inter-field transportation level performing dispatching, scheduling and routing, and at the in-field level providing coordination. The on-line central computation of solutions of problems at both levels is not practically possible due to the computational complexity of the problem. Therefore, computation is expected to be done both centrally and in a distributed fashion. This can be achieved by decoupling the scheduling from the traffic planning problem so that effectively the dispatcher *abstracts* the detailed in-field traffic patterns for individual operations and treats them as simple numbers expressing the duration of in-field operations for any given machine assignment. This means that the new in-field traffic plan could be computed locally and that only the updated estimated task time must be communicated to the central dispatcher. Communication between every machine and the dispatcher may require excessive messaging among the members of the team. If a local coordinator exists, it is much easier for this coordinator to distribute the updated plan to all involved parties and verify its reception before signalling its initiation. Of course, if the coordinator fails for some reason, another machine could take its role using some well defined protocol.

Within a fleet management system, data and information needs to be exchanged between the central dispatching station and the vehicles, as well as between vehicles. Communication between a vehicle and the central dispatching unit is typically long distance, with ranges that may exceed hundreds of kilometres. Each vehicle must send periodically, preferably in real-time its position and operational status to the dispatcher. Medium-size latency, relatively low bandwidth and packet drop are acceptable in this mode of communication because real-time vehicle monitoring for slow-moving agricultural vehicles is not a demanding application. This is already achieved by commercial fleet management systems using established commercial satellite and GSM cellular telecommunication technologies. On the other hand, vehicle-to-vehicle (V2V) communications for coordinated motion control and collaborative collision avoidance will require *high-bandwidth, low-latency, high reliability, relatively long range* and *relatively high mobility* networking. The driving force behind V2V technologies is the car manufacturing industry. Given the strict safety requirements from V2V technologies the most promising existing technologies are DSRC and WiMax, provided that a worldwide standard will be achieved. MBWA promises to be superior to both of them, but it has not been implemented yet.

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