CELL-BASED APPROACHES TO AUTOMATIC VEHICLE LOCATIONING

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Astract: In many public transport applications it is necessary to identify and locate vehicles in real-time. The development of a novel cell-based automatic vehicle locationing system (AVL) for application in the bus industry is presented. The cell-based approaches combine the existing AVL technologies with the cellular technologies to form a simultaneous bus polling AVL system. The frequent updated information collected from the AVL-equipped bus can be used to support public transport priority at signalized junctions and passenger information systems. The SIGSIM microscopic traffic simulator (Law, 1997) will be modified to simulate the proposed cell-based AVL.

1. INTRODUCTION

The development of a novel cell-based Automatic Vehicle Locationing system (AVL) is presented in this paper. The fundamental advantage of the cell-based approach to AVL is that direct communication between the vehicles and the cell-based-station enables the vehicle fleet to be polled simultaneously.

In Section 2, a review of the main technologies for AVL (Scorer, 1993) are given. The capabilities of some commercially available AVL systems are analyzed and results are presented.

A review of cellular communication technologies (Catling, 1994, Flood *et al*, 1991, Spragins *et al*, 1991) and the application of cellular communication technique to increase the data transmission for AVL systems is given in Section 3. It is suggested that cellular communication technology is one way to increase the communication capacity between the vehicle and the AVL control centre. Beacon-based products are considered for the cell-based AVL application due to its high accuracy and suitability.

In Section 4, system architecture for a generic cell-based AVL system is presented. The technique uses the existing AVL system and combines it with the cellular technologies.

The fundamental advantage of the proposed cell-based approach to AVL is that direct communication between the vehicle and the cell-based-station enables the vehicle fleet to be polled simultaneously. This type of vehicle polling technique would reduce vehicle fleet polling time by a considerable amount hence enabling frequent update of the bus position in real-time.

Modelling of the cell-based AVL is given in Section 5. The SIGSIM (Law, 1997) microscopic traffic simulator will be modified to enhance the cell-based AVL system.

2. REVIEW OF AVL TECHNOLOGIES AND COMMERCIALLY AVAILABLE AVL SYSTEMS

A survey of literature on Automatic Vehicle Locationing led to the identification of three major cores in AVL technologies namely:

(a) beacon-based systems (Figure 1 and 4);
(b) satellite-based system (Figure 2); and
(c) terrestrial radio-based system (Figure 3).

The basic components of the above AVL systems can be grouped into five broad categories:
(1) On-vehicle equipment - for tracking the position of the vehicle in real-time and control of a variety of on-bus peripherals.
(2) Vehicle position references (eg. roadside beacon) - for positive location of vehicle position and for use to compensate for any location errors.
(3) Control centre - where operational staff can monitor the position of the bus in real-time, compare their actual positions with the schedule and take appropriate actions in the event of problems.
(4) Communication systems - for communications between control centre and the vehicle.
(5) Bus stop equipment - which displays to passengers the destination of the next few buses together with its arrival time.

2.1. Beacon-based AVL Systems

The beacon-based AVL systems are similar to the dead-reckoning systems used in dynamic route guidance (Anagnostopoulos *et al*, 1992). With fixed route transit (such as buses and trams), distance travelled is sufficient for vehicle locationing. Typically, the beacon-based AVL systems (Figure 4) consist of:

On-vehicle equipment;
Roadside beacon equipment;
AVL Control centre; and
Communication systems.

The on-vehicle equipment is used for measuring the location of the vehicle. Each vehicle is equipped with some form of on-board unit (OBU) and a precalibrated odometer. The on-board unit can be configured to control a variety of on-bus peripherals, such as ticket machines and in-vehicle passenger displays. The on-board unit is also capable of storing information (eg Bus ID, route ID, distance between each stop, the names of the stops and the schedule running times) for use in determining any deviation from schedule by comparing stored timetable information with current bus location. Vehicles are also fitted with a receiver (and transmitter for two-way communication) for communicating with the roadside beacons. Before the bus leaves the depot, the OBU is initialised with the relevant data such as route number, bus ID code etc, and the odometer is set to zero. The vehicle position is tracked by measuring distance travelled, using the pulses generated from a precalibrated odometer. As the bus follows known routes, distance travelled is sufficient for continuous locationing. The roadside beacon and/or the bus doors opening and closing are used to compensate for any accumulated errors. The error can accumulate from temporary diversions which may arise from accidents, wheel spins in icy conditions, overtaking, lane changing, turning corners, as well as the state of the inflation of the tyres.

The roadside beacons are used for positive location of vehicle position to compensate for any location errors. Roadside beacons are located at the start of the bus route and at intermediate positions along the route and are usually mounted out of reach on, for example, lamp posts. The main task of the roadside beacons are to transmit some form of location code to any passing buses. Two modes of transmission have been identified, active mode and dormant mode. In active mode, beacons transmit the location code continuously. In dormant mode, beacons only transmit the location code to the passing bus on request. In order to communicate with the active beacons, vehicles must be fitted with a receiver. To communicate with the dormant mode beacon (two-way communications), both vehicle and the beacon must be fitted with transmitter and receiver. When the bus passes along its route, it transmits a "request for location" message. When a beacon receives this message it wakes-up from its dormant mode and transmits some form of location code to the vehicle. The passing vehicle receives and stores information transmitted by the beacon and resets the odometer count to zero. Several methods of communication between the vehicle and the beacon can be used. The most common ones are, infra-red, microwave, UHF, radio wave or loop-based methods.

The main function of the AVL control centre is to communicate with the vehicle, monitor the positions of the vehicles in real-time, compare their actual positions with the schedule and take appropriate actions in the events of problems. The hardware platform of the control centre typically consists an ETHERNET-based computer network with radio data server, host computers and workstation computers with hardware bases on the DEC VAX/VMS family computers.

Communication between the vehicle and the control centre enables updating of the control computer on the vehicles current location. Both the vehicle and the control centre are equipped with radio transmitter and receiver. The control centre transmits/receives information to/from the vehicle in the fleet in the form of a telegram and *vice versa*. The methods that can be used for communication between the vehicle and the control centre are summarised by (Burditt, 1993) as:

Private Mobile Radio,
Public Access Mobile Radio (Band 3),
Mobile Public Data networks,

Cellular Phone Services, and
Satellite Services.

The second method is used by London Transport and MerseyTravel in the UK. The control centre transmit an "individual enquiry message", which will received by the whole fleet, but only the individual vehicle that the message refers to will respond. Many of the beacon-based AVL systems poll the vehicles sequentially, and thus an update on vehicle position is reported at a certain rate. In most beacon-based AVL systems, one additional radio data channel is set aside and voice communication is available for use in case of emergency.

2.2. Satellite-based Systems

The Global Positioning Systems (GPS), which consists of 24 satellites, orbiting some 20,200 km above the surface of the Earth can be use to form the basis of an AVL system (see Figure 2). GPS allows determination of location from the transmission of long-range radio waves from satellites. The system will allow worldwide coverage, but performance is impaired by the shielding effects of urban buildings. Basically, a three dimensional position (longitude, latitude and height) is determined from the time it takes for the three satellite transmissions to be received by the vehicle equipment, consisting of an on-board processing unit, a satellite receiver and a communication system for contact with a control centre. A fourth satellite is required for transmission of the accurate GPS timing. The vehicle unit consists of a clock and needs to be synchronised. A fifth satellite is used to check on the other four satellites (Scorer, 1993). The GPS system is owned and serviced by the US Department of Defense. Currently, there is no associated charge for using the GPS data but this could change with time and is entirely dependent on the goodwill of the US Department of Defence. For GPS systems, an accuracy of the order of a hundred metres is offered (Stewart, 1993). The accuracy of the system can be increased by using differential techniques (Cheong, 1992)

2.3. Terrestrial Radio-based systems

The Terrestrial Radio-based systems (Figure 3) make use of the dedicated ground networks by comparing low frequency transmissions received by the vehicle to calculate the position of the vehicle with respect to the radio navigation network. The OMEGA system consists of eight radio transmitters around the world. The on-board units and the receivers measure phase differences of continuous radio waves, which are transmitted on frequencies of 10-14 Hz (Scorer, 1993). From these phase differences the vehicle location within the radio network can be determined, and translated into latitude and longitude co-ordinates. The system is thought to have an accuracy of the order of a few thousand metres, although this is significantly increased when using differential techniques (as is the case of the TERRAFIX system, which quotes an accuracy of 50m).

The Datatrak system works on similar principles but is only a country-wide system. In Britain, there are thirteen radio transmitters which operate on frequencies of 133kHz and 145 kHz (Banks, 1992). The in-vehicle units measure phase differences and this data, combined with direction and speed, are transmitted on a UHF channel to various base stations around the country. The information is then forwarded to one of five regional computers which determine vehicular position. This information is then sent to operator control centres via cables.

The CURSOR system makes use of existing radio stations (e.g. public radio broadcast station or television stations). Phase differences from three independent transmitters are measured at the vehicle receiver and at a receiver in the base station. The base station then transmits its readings to the vehicle receiver in order that its position can be computed. The system has to be initialised at the start of each day. The CURSOR system is currently under trial and it is not yet a feasible option.

2.4. Commercially Available AVL Systems

In the survey of commercially available AVL products, several companies and organizations marketing the AVL products and selected bus companies who use the AVL products have been contacted. The AVL systems investigated in the survey were:

(a) LIOplus system, manufactured by Häni-Prolectron, a subsidiary of Siemens;
(b) BUS-TRACKER system, manufactured and marketed by Peek Traffic;
(c) Star-Tracker system, manufactured and marketed by Marconi;
(d) TERRAFIX AVL system; and
(e) Datatrak system manufactured and marketed by Securicor Datatrak Ltd.

It should noted that, other AVL products are available, but were not investigated as part of this project.

Some characteristics of existing AVL systems are shown in Table 1. A description of each product can be found in (Smith *et al*, 1994). The characteristics of these systems have been checked and updated as part of the project reported in this paper.

2.5. Application of AVL to Public Transport (Buses)

In many public transport applications it is necessary to identify and locate vehicles as they leave or enter depots and travel through the road network at any time. This can be achieved by continuous locationing of the vehicles using AVL technologies. Three main applications of AVL systems in public transport are: bus fleet control; passenger information systems; and bus priority at signal controlled junctions. The main benefits that could be gained by use of AVL in public transport sectors include: improved adherence with schedules; greater reliability of service; and improvement in service quality perceived by passengers.

In the case of bus fleet control use of AVL systems enable bus operators to monitor the progress of their vehicles from a control centre. Information on deviation from schedule can be relayed to the driver who may able to correct the deviation. By use of location information at the control centre any disruptions can be quickly identified and remedial action taken. One other use of AVL for bus fleet control is to gather statistical data for future bus service schedules and planning.

One application of AVL in the area of passenger information system is the identification and location of the bus which can be used to update information displays at bus stations and selected bus stops, indicating the time of arrival of the next bus on each route. The removal of uncertainty for waiting passengers will boost their confidence in the public transport system and perhaps lead to increased patronage. A further possible application of AVL for passenger information is the provision of in-vehicle displays. These could indicate the location of the next stop and be automatically updated each time the vehicle passes a roadside beacon. This would remove a source of potential passenger anxiety and should lead to increased patronage.

Traffic can suffer considerable delays whilst waiting in queues at a signalled intersections. As buses have a much higher passenger carrying capacity than private cars there are strong social and economic grounds for giving priority to buses over other traffic. This may be achieved at traffic signals by detecting approaching buses and calling (or extending) the green signal as appropriate. With suitable equipped detectors (Figure 4), a bus can communicate with the traffic signal controllers for priority at the signalised junctions.

2.6. Limitations of the Existing AVL Systems

Several limitations of the existing AVL systems are recognized, they may be summarized as:
(a) Limited frequency channel of the AVL systems: normally, only one data channel (or one duplex data channel: one channel for transmitting and one channel for receiving information) is available for communication between the vehicle and the control centre.

(b) Direct communication between vehicle and control centre which results in only one bus at a time being able to communicate to the AVL control centre.
(c) Most of the AVL systems do not contribute to priority at traffic signals. Some AVL systems support traffic light priority but the technique used for estimating a vehicle approaching the junction is coarse (e.g. Bus Tracker system).

Better AVL Systems are needed for public transport to improve passenger information systems and measures for bus priority at traffic signals and in networks. One way of achieving these goals is to continuously locate the position of vehicles in real-time and to frequently transmit updated information from the vehicle to AVL control centre. It was suggested that cellular communication technology is one way to increase the communication capacity between the vehicle and the control centre hence increasing the polling frequency of each bus in the fleet.

3. REVIEW OF CELLULAR COMMUNICATION TECHNOLOGIES AND THE APPLICATION OF CELLULAR TECHNOLOGIES TO CELL-BASED AVL

3.1. The Cellular Concept

The basic concepts behind cellular radio are not complex, and indeed are not new dating back to 1949 (DiPiazza *et al*, 1979). In the cellular communication technique, the area to be covered by the cellular system is divided up into a number of cells, and each cell has a radio base station (see Figure 8), with each base station operating on a different set of frequencies to those in adjacent cells, so as to avoid co-channel interference. The total number of radio frequencies, or channels, available to the system is split up into a number (N) of channel groups or sets. The channels are then allocated to the cells, one channel set per cell, on a pattern which repeats to fill the number of cells required. Figure 5 is an example of multiple re-use of seven frequencies. Multiple re-use of frequencies throughout the coverage area is made possible by limiting transmitter power and antenna height at the base station and maintaining adequate distance between base stations. Thus, each channel set may be re-used many times throughout the coverage area. The system capacity can be increased provided that all the users are not concentrated in one cell at a time.

When a channel is re-used there is a risk of co-channel interference within a cell from a base station in another cell on the same frequency. However, provided the (D) mean re-use distance (Figure 5) is kept large enough in relation to radius of the cell (R), i.e. the so-called D/R ratio is high enough, the probability of interference can be contained to controllable levels. A recommended value for the D/R ratio is 4.6 (Walker, 1990). Techniques for control of co-channel interference are detailed in (Walker, 1990; Jiang *et al*, 1994; Rappaport 1994).

In a cellular network, the service area is split up into a number of location areas each with its own area identity code Figure 7. This identity code is then transmitted regularly from all base stations in the area. As a mobile unit (ie a vehicle) moves about the network, from time to time it will select a new base station to lock onto (ie. automatic switch of frequency). The mobile unit will check the area identity code transmitted by the base station, and when it detects a change, indicating that the mobile unit has moved to a new location area, it will automatically inform the base station of its new location by means of a signalling interchange with the base station. The base station will then inform the control centre the mobile unit's new location. In this way the control centre can keep a record of the current location area of each mobile unit.

The fundamental advantage of the cellular approach is that more users can be accommodated than with other mobile communications system - as long as users are not concentrate in one cell most of the time. Therefore in a highly populated areas, smaller cells are used. Figure 6 shows a typical city cell plan. In the city centre, the mobile unit traffic is likely to be concentrated, the cell size is therefore smaller in this area.

A cellular communication network is available in U.K. Tables 2 and 3 are a summary of the radio communication channels available in U.K. and Europe. As can be seen from these tables, the total channels available for application are limited. Multiple re-use of frequencies is one solution to the frequency limitation problems. Information obtained from London Transport, MerseyTravel and Peek Traffic confirmed that, it is difficult to obtain licenses for additional radio channels in U.K.

3.2 Application of Cellular Technology concept to Automatic Vehicle Locationing

It is suggested that the concept of cellular communication can be applied to the existing AVL systems to increase the system capacity. The ideas which are discussed in detail in the next section can be summarized as follows:

- Divide the coverage area into cells;
- for each cell use a traffic signal controller equipped with radio facilities as a cell-base-station;
- re-use one radio frequency channel for the cells;
- the vehicles are to communicate directly to the cell-based-stations via radio channels and communication may occur simultaneously;
- the cell-based-stations communicate simultaneously with the AVL control centre;
- beacons are used for registration of vehicle movement between cells; and
- co-channel interference caused by multiple re-use of one frequency can be limited by limiting transmitter power and antenna height at the cell-base-station and the cell border beacons for handling information of the vehicle at the cell border.

It is possible to tap the cell-based AVL system on the existing cellular phone networks. Detail of the costs for licensing the cellular phone networks for AVL application have not been investigate in this research project.

4. CELL-BASED APPROACHES TO AVL SYSTEMS

4.1. Basic Components of a Generic Cell-Based Automatic Vehicle Locationing System

Figure 9 depicts the proposed cell-based AVL system architecture. The cell-base-station described in the text refers to the traffic signal controller equipped with radio antenna and radio data transmission systems for use at a specified radio transmission power. The basic components of this AVL systems can be grouped into five categories:

(a) On-vehicle equipment;
(b) Vehicle position references (eg roadside beacon);
(c) AVL control centre;
(d) Cell-base station; and
(e) Communication system.

On-vehicle Equipment

The on-vehicle equipment and their function in the cell-based AVL system is the same as those described in Section 2.1 excepted that the vehicle must be fitted with both transmitter and receiver to provide two-way communication with the roadside beacons.

Roadside Beacons

Section 2.1 provided details of the roadside beacons. The additional tasks of the roadside beacons in the cell-based approach are to transmit/receive information from the passing vehicles and to communicate with the cell-base-station. Added to the above role the beacons located at the border of the cells are to notify the cell-base-station on the vehicle entering/leaving the cell; this enables the cell-base-station to keep track of the vehicles entering and leaving the cells. This type of technique requires the roadside beacon to be able to handle two-way communications: i.e. to transmit and receive information (Häni-Prolectron offer this type of equipment). An example of this product is the traffic light priority IFIS beacon-based AVL system). Several methods of communication between the vehicle and the beacon can be used, the most common ones are, infra-red, microwave, UHF, or radio wave (Burditt, 1993). Beacons communicate with the traffic signal controllers via cable lines.

Control Centre

Detail of the AVL control centre is given in Section 2.1. The control centre in the cell-based AVL system communicates with the cell-base-station instead of communicating directly to the vehicles as in the case of conventional AVL systems. The control centre transmits/receive information to/from individual vehicle via the cell-base-station. The host computer (or computer network stations) for the cell-based approach should be equipped with several input/output ports for simultaneous data transfer between the cell-base-stations.

Cell-base-station

The cell-base-station consist of a traffic signal controller equipped with radio transmit/receive facilities and radio transmission power control. The main functions of a cell-base station are:

(a) Communicate with beacons: The cell border beacons notify the cell-base-station of vehicles present within that cell by transmitting the ID of the passing buses to the cell-base-station.
(b) Communicates with vehicles: The cell-base-station communicate with the buses within their cell via radio data channel. They collect data from the vehicles within their cell and transmit these data to the AVL control centre. They receive information from the AVL control centre and transmit the received information to vehicles.
(c) Communicate with AVL control centre: The cell-base-station communicates with the control centre via cable lines. They receive location data from the vehicles and send the vehicle information to the control centre on request; and receive information from the control centre and transmit the received information to the vehicles.

Communication Methods

Communication between the control centre and the cell-base-station are via cable lines. The beacons are connected to the cell-base-station also via cable lines. The methods that can be used for communication between the vehicle and the cell-base-station include:

- Private Mobile Radio,
- Public Access Mobile Radio (Band 3),
- Mobile Public Data networks, and
- Cellular Phone Services.

4.2. Function of the Cell-based AVL System

Simultaneous interchange of data via radio data communication between the vehicles ↔

cell-base-station ↔ public transport control centre forms the basic function of the cell-based AVL system. The vehicle could communicate to the cell-base-station with the methods listed below:

(a) vehicle ↔ roadside beacon → cell-base-station (radio-beacon-based system);

or

(b) vehicle ↔ cell-base-station (radio-based system).

For method (a), when the buses passes along its route, it transmits a "request for location" message together with some relevant information such as bus ID to the roadside beacon. When a beacon receives this message it communicates with the cell-base-station to put the "bus ID and request for polling message" for the passing vehicles. When the cell-base-station receives the information from the beacon, it stores the ID of vehicles in the "vehicle ID list" and calls each vehicle in the "vehicle ID list" in turn. When a new vehicle enters the cell, a new vehicle ID is added to the "vehicle ID list" and if the entering vehicle is in the state of unfinished polling from the previous cell, priority polling is given to the vehicle. When a vehicle leaves the cell, the ID of the vehicle is deleted from the list and the polling state of the vehicle is passed to the boarder beacon and it is the task of these boarder beacons to communicate to the cell-base-station in the cell which the vehicle intends to enter. When the cell-base-station polls the last vehicle in the "vehicle ID list" and no new vehicle enters the cell, it goes back to the beginning of the list and continues to poll the vehicles in the list until it receives information from the beacon informing of new vehicles entering the cell. After polling of each vehicle, the cell-base-station transmits the information received from the vehicle to the public transport control centre via cable lines. The public transport control centre passes the instructions to the vehicles via the cell-base-station. The cell-base-station transmit the instructions received from the public transport control centre to the vehicle.

For method (b), the vehicle communicates directly to the cell-base-station. This method requires fewer beacons per cell but special techniques are needed to keep track of the vehicles entering/leaving cells.

Although AVL systems are coming more widespread and are able to achieve accuracy to around 10m, the direct radio-link to the control centre has already been identified as a bottleneck. Consider a fleet of M buses in an area, where one current AVL system is used and its polling rate is 4 buses per second (eg BUS TRACKER installed in London Transport). The total polling time for the bus fleet will be M/4 seconds. For cell-based AVL, if the area is divided into N cells according the distribution of buses, on average, there will be M/N buses in each cell. If the same BUS TRACKER system is used and the polling rate of these cell base stations is also at 4 buses per second, the polling time of each cell will be M/(N*4) seconds. Because the cell base stations poll the buses in each cell simultaneously, the total polling time is M/(N*4) seconds. The total polling time can be reduced further, if the area is sub-divided into smaller cells.

In the cell-based AVL, within one cell, each vehicle is being polled sequentially but all the cells are polling their vehicles simultaneously hence the cell-base approach increases the data transmission capacity of the AVL system.

5. MODELLING OF CELL-BASED AVL USING SIGSIM

SIGSIM will be enhanced to represent the cell-based AVL system. SIGSIM is a micro-simulation model for simulating individual vehicles on a signal controlled road network using a mathematical model developed by (Gipps, 1981). SIGSIM was developed jointly between Transport Operations Research Group (TORG), Newcastle University and Centre for Transport Studies (CTS), University College London. The modelling of cell-based AVL systems in SIGSIM is divided into six parts:

- modelling of cells,
- modelling of cell-base-station,
- modelling of roadside beacons and cell border beacons,
- modelling of the AVL equipment,
- modelling of odometer and errors associated with odometer readings, and
- modelling of bus stops and passenger information system.

6. CONCLUSIONS

Several limitations of the existing AVL systems are recognized. Direct communication between vehicle and control centre with one radio channel data transmission allows only one bus to polled at a time. Most systems do not implement public transport priority. The proposed cell-based approach polls the vehicles simultaneously hence increasing the data transmission capacity between the vehicle and the AVL control centre. The technique uses the existing AVL system and combine it with the cellular technologies. Little modification is required to turn the existing AVL sequential polling system to the simultaneous cell-based AVL polling system. With frequently updated location information available in the vehicle, traffic computer and the public transport control centre, it is possible for traffic light priority to be requested at any appropriate point on the approach to the signalised junctions.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the UK Engineering and Physical Sciences Research Council who have funded this research.

REFERENCES

Anagnostopoulos, P., Papapanagiotakis, G. and Gonos, F. (1992) PAN-DRIVE: A vehicle navigation and route guidance system. **Proc. Vehicle Navigation and Information Systems, IEEE International Conference,** Oslo, Sept 2-4, 1992. pp. 14-19.

Banks, K. (1992). Datatrak automatic vehicle location system in operation in U.K. **Proc. 25th ISATA,** Florence, May 1992. pp. 721-728.

Burditt, D. (1993) Real-time location and mobile data applications for public transport systems. **Proc. of 24th Annual Public Transport Symposium,** University of Newcastle, Mar 30 - April 1, 1993.

Catling, I. (1994) **Advanced Technology for Road Transport: IVHS and ATT.** Artech House, Inc., Boston - London.

Cheong, M.S. (1992) Integrated land and coastal navigation using a differential GPS receiving system. **Proc. Vehicle Navigation and Information Systems, IEEE International Conference,** Oslo, Sept 2-4, 1992. pp. 380-386.

DiPiazza, G.C., Plitkins, A. and Zysman, G.I. (1979) AMPS: The cellular testbed. **Bell System Technical Journal,** Vol. 58, No. 1, Jan 1979, pp215-248.

Elkins, P.J. (1993) The German approach to automatic vehicle location and passenger information systems. **Proc. 24th Annual Public Transport Symposium,** University of Newcastle upon Tyne, April 1993.

Flood, J.E., Hughes, C.J. and Parsons, J.D. (1991) **Personal & Mobile Radio Systems.** Macario, R.C.V. (Ed) Peregrinus, London.

Gipps P.G. (1981) A behaviourial car-flowing model for computer simulation. **Transportation Research 15B,** 105-111.

Jiang, H., Rappaport, S.S. (1994) Channel borrowing without locking for sectorized cellular communications. **IEEE Transactions on Vehicular Technology.** Nov 1994, V. 43, No. 4, 1067-1077.

Law, M. (1997). TORG SIGSIM User Guide. Transport Operations Research Group Report. Transport Operations Research Group, University of Newcastle Upon Tyne, England.

Rappaport, S. (1991) The multiple-call hand-off problem in high-capacity cellular communications systems. **IEEE Transactions on Vehicular Technology.** Aug 1991, Vol. 40, No. 3, 546-557.

Rappaport, S., Jiang, H. (1994) CBWL: A new channel assignment and sharing method for cellular communication systems. **IEEE Transactions on Vehicular Technology.** May 1994, Vol. 43, NO. 2, 313-322.

Scorer, T. (1993) An overview of AVL (Automatic Vehicle location) technologies. **Colloq. Vehicle Location and Fleet Management System,** Inst. of Electrical Engineers, London Jun 8, 1993.

Smith, M.W., Nelson, J.D., Bell, M.G.H. and Dickinson, K.W. (1994) Developing the concept of buses as probes: The integration of automatic vehicle locationing and urban traffic control systems. **Proc. 7th Symposium on Transportation Systems,** TianJin, 1994. pp 637-642.

Spragins, J.D., Hammond, J.L. and Paulikowski, L. (1991) **Telecommunications - Protocol and Design.** Reading: Addison-Wesley.

Stewart, J. (1993) Vehicle locationing and positioning monitoring system using satellite navigation and cellular phone. **Colloq. Vehicle Location and Fleet Management System,** Inst. of Electrical Engineers, London Jun 8, 1993.

Walker, J. (1990) **Mobile Information Systems.** Artech House, Inc., Boston - London.

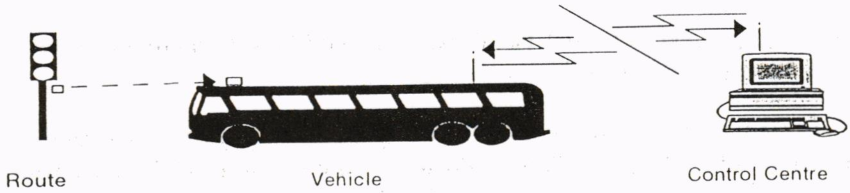


Fig 1. The Basic Components of a Beacon-based AVL System

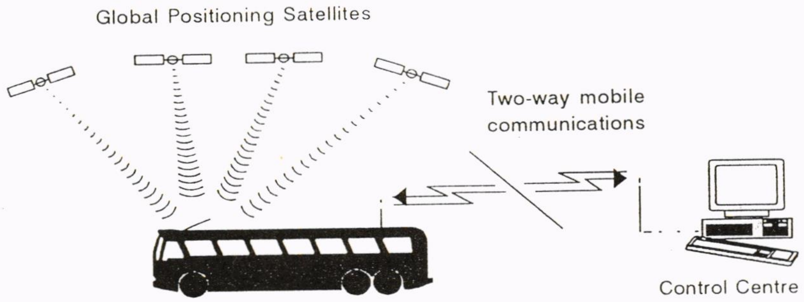


Fig 2. GPS-based AVL System

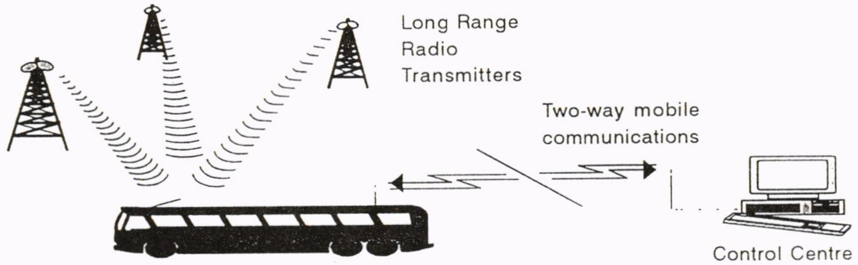


Fig 3. Land-based Radio AVL System

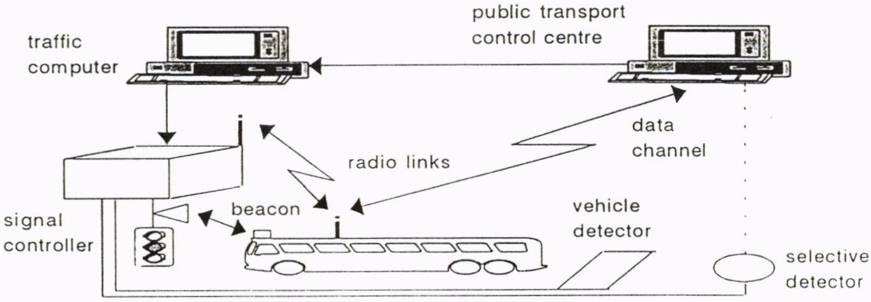


Fig 4. Priority call AVL System

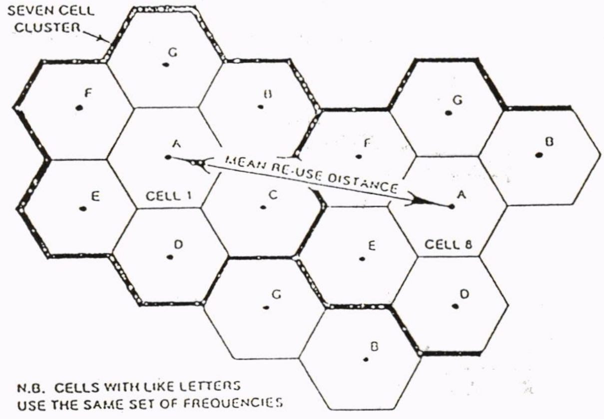


Figure 5 Multiple Re-use of Frequency (N=7)

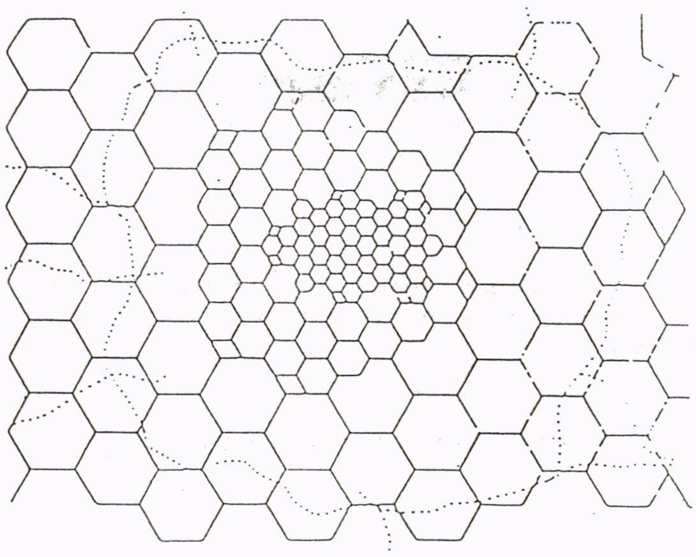
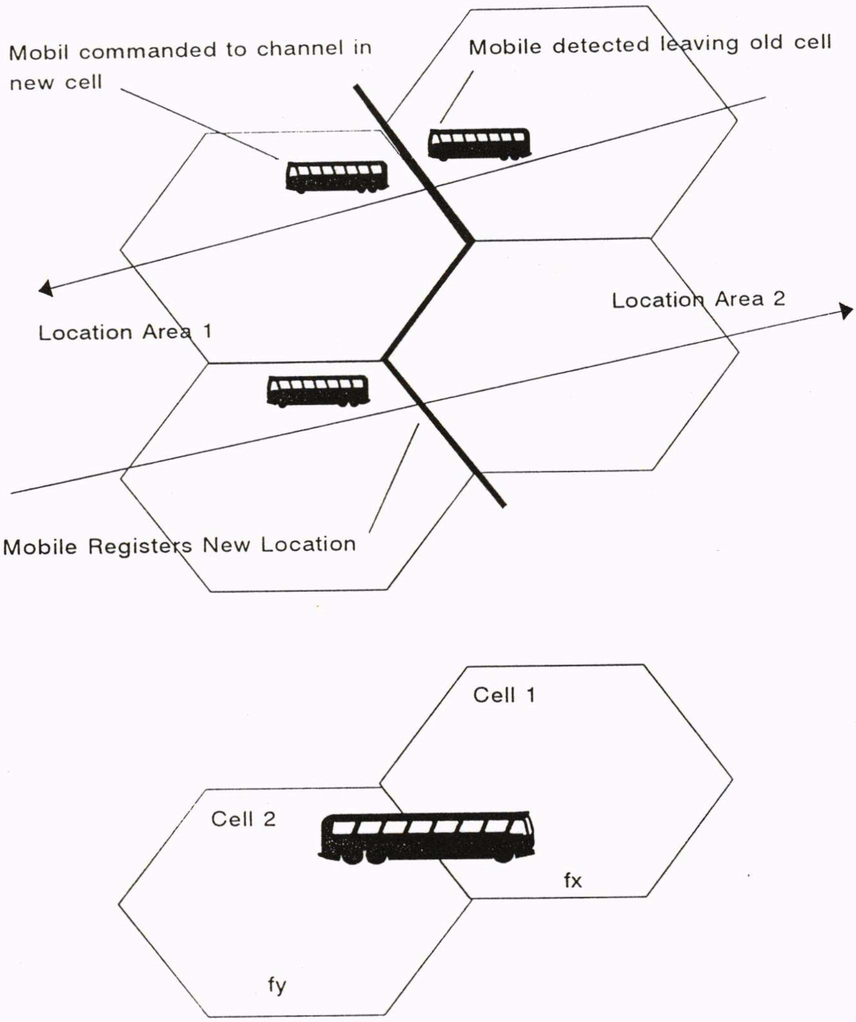


Figure 6 Typical City Cell Plan



Hand-off: when the mobile subscriber moves from cell 2 to cell 1, his channel frequencies will be changed from the set fy to the set fx automatically.

Figure 7 Mobile Location Registration

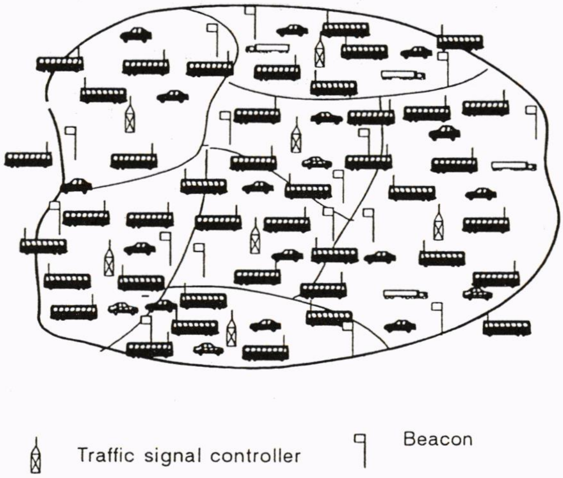


Figure 8 Application of Cellular Communication Concept to AVL

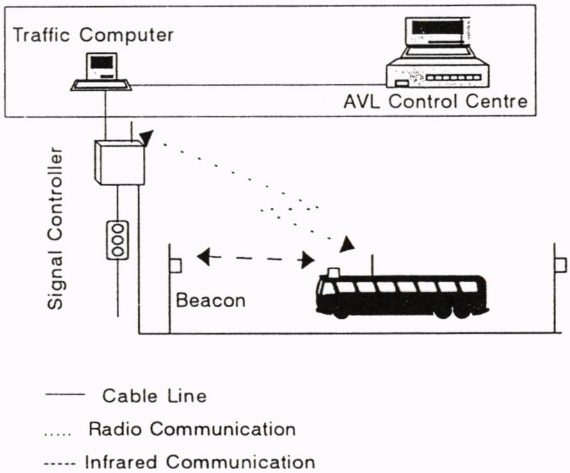


Figure 9 Cell-based AVL System Architecture

Table 1. Summary of the Commercially Available AVL Systems

SYSTEMS	TYPE	REPORTED ACCURACY	COMM. METHOD	POLLING TIME (veh/sec)
LIO-PLUS	Beacon-based	~10m	Radio	10 Stadtwerke, Frankfurt
BUS-TRACKER	Beacon-based	~10m	Radio	4 MerseyTravel, London Transport
BUS-TRACKER	GPS	<100m	Radio	1 London (Airbus)
BUS-TRACKER	TAG		Radio	
DATATRAK	Radio/GPS	50m	LF/UHF	1.68 s for position calculation
STAR-TRACK	GPS/Radio	25m	Any	Shutle bus (M'Airport)
TERRAFIX	Radio	50m	HF Radio	1 PMT bus

Table 2 Frequency Bands Allocated to Private and Public Mobile Radio

Band Name	Type of Service	Frequency Band MHz	Maximun effective radiated power (ERP) watts
LOW All channels are at 12.5 kHz spacing	Mobile transmit Two-frequency simplex	71.50-72.80 76.95-78.0	25
	Base transmit Two-frequency	85.00-86.30 86.95-88.00	25
	Single-frequency simplex	86.30-86.70	5
MID/HIGH All channels are at 12.5 kHz spacing	Base transmit Two-frequency simplex	162.05-163.025 165.05-168.237	25
	Mobile transmit Two-frequency simplex	157.45-160.5375 169.85-173.0375	25
	Single-frequency	158.5375-159.925	5
Band III All channels are at 12.5 kHz spacing	Mobile transmit trunked duplex	192.50-199.50	20
	Base transmit trunked duplex	200.50-207.50	20
UHF Most channels are at 12.5 kHz spacing	Base transmit Two-frequency simplex	440.0-446.0 453.0-454.0 456.0-457.0	25
	Mobile transmit Two-frequency simplex	425.0-429.0 459.0	25
UHF Cellular All channels are at 12.5 kHz spacing TACS + ETACS	Base transmit Two-frequency duplex	917-933 and 935-950	10
	Mobile transmit Two-frequency duplex	872-888 and 890-905	0.6/1.6/4
*Cordless CT2	Duplex	864-868	0.1
*Pan European *Cellular or *GSM	Base Mobile	950-960 905-915	requred to operate with power control
*DSSR	Simplex	933-935	1
*PCN's	Duplex	Band in 1710-1880	as yet unspecified

* systems use digital modulation

Table 3 Frequency Bands Allocated to Cellular Communication in UK and Europe

	GSM	IS-54	CT2	DECT
Forward band (MHz)	935-960	869-894	864-868	1880-1900
Reverse band (MHz)	890-915	824-849	864-868	1880-1900
Multiple access	TDMA	TDMA	FDMA	TDMA
Duplex	FDD	FDD	TDD	TDD
Carrier spacing (kHz)	200	30	100	1728
Channels per carrier	8	3	1	12
Bandwidth/two-way channel (kHz)	50	20	100	144
Channel rate (kb/s)	271	48.6	72	1152
Modulation	GMSK	DQPSK	FSK	GMSK
Modulation efficiency (b/s/Hz)	1.35	1.62	0.72	0.67
Voice rate (kb/s)	22.8	13	32	32
Control channel name	SACCH	SACCH	D	C
Control channel rate (b/s)	967	600	200	6400
Control channel message (bits)	184	65	64	64
Control channel delay (ms)	480	240	32	5