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Telecommunications network routingField of the Invention

5 The invention relates to the field of
telecommunications network routing, and in particular the
field of opportunistic networks. For example, embodiments
of the invention relate to telecommunications networks in
geographic areas in which there is little or no permanent
10 wired network infrastructure.

Background of the Invention

 The performance of civil and military operations, such
15 as responses to emergencies and operations in remote or non-
friendly territory, can be seriously compromised if
communication links are poor. Unfortunately, communication
links often are poor in such territories, either as a result
of natural or military disruption of pre-existing permanent
20 links, or as a result of there being no or few such
permanent links in the first place.

 A great deal of research has been done in recent years
into the performance of opportunistic telecommunications
networks, which do not rely on the existence of pre-existing
25 fixed links. Many such networks, for example networks
established on an *ad hoc* basis between mobile phones or
between road vehicles, require a high density of devices
able to participate in the network; clearly, that will often
not be available in post-disaster, conflict or similar
30 areas. Furthermore, many operations have requirements

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beyond mere connectivity - for example, security requirements may necessitate restricting data to trusted network devices, and in many cases to trusted network devices specifically rated to handle the sensitive
5 information - which can reduce still further the number of available nodes in a network.

Most work in this area has concentrated on devising and investigating different forms of routing. Some work has also been done considering the best choice of bearer for
10 links. One approach adopted in the area of tactical (military) communications is provision of dedicated communications unmanned aerial vehicles (UAVs). However, UAVs are very expensive. Another approach is to mount network communications devices on vehicles that have a
15 primary function that is not communications, for example, transport aircraft. By extending the range of possible platforms that can be employed, the number of available platforms can be increased significantly; however, typically the non-dedicated vehicles will be available only
20 intermittently, according to the requirements of their primary function. Networks incorporating such "non-communication assets" are referred to as "opportunistic networks", often taken to be a sub-class of Disruption/Delay Tolerant Networks. Such networks have been studied with a
25 view to optimising the routing of communications data over their links, in view of their intermittent nature.

In "Routing Strategies in Multihop Cooperative Networks", IEEE Transactions on Wireless Communications, Vol. 8, No. 2, February 2009, Gui *et al* present a study of
30 outage performance, taking into account the fading

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characteristics and broadcast nature of wireless channels,
for three different routing strategies: optimal routing, in
which the source-to-destination path with the largest
minimum signal-to-noise ratio (SNR) is chosen; ad-hoc
5 routing, in which the hop with the highest SNR is chosen at
each node from available next hops; and N-hop routing, in
which the path with the largest minimum SNR over groups of N
hops is chosen. Optimal routing is found to give the best
outage performance, but at the expense of greatly increasing
10 complexity of calculation for routing over more and more
hops. Ad-hoc routing suffers from greater outage, but the
complexity of calculation is the same regardless of the
number of hops. N-hop routing is a compromise that can
provide a good trade-off between outage performance and
15 complexity of calculation.

Despite these various efforts, there remain
environments in which there are unlikely to be sufficient
dedicated communications nodes in a deployable network to
provide communication links of the desired quality. Of the
20 approaches discussed above, the use of communication nodes
on non-communications assets to work on an opportunistic
basis is a more cost-effective approach than using dedicated
communications UAVs, but such non-communications assets
provide only "nodes of opportunity", which will usually be
25 far from optimal. Prior-art attention has generally been
focused on mobile ad hoc network (MANET) issues.

The present invention seeks to mitigate the above-
mentioned problems.

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Summary of the Invention

The present invention provides, in a first aspect, a network controller for controlling a telecommunications network comprising a plurality of vehicles each including a telecommunications device, the network controller comprising:

a network configuration database, containing data representing the configuration of the network;

an assets database, containing for each vehicle (i) data representing planned movements of the vehicle in a geographic area, the vehicle having a planned route from a first location to a second location, and (ii) data representing parameters for acceptable variation in said route;

an information exchange requirement (IER) database, containing data representing expected future network loading;

an optimisation engine configured to calculate from the data stored in the network configuration database, assets database and IER database, a set of routes for the vehicles, subject to the parameters for acceptable variation, that optimises the availability of the telecommunications network in the geographic area; and

a tasking-order dispatcher, configured to generate tasking orders for transmitting to the vehicles from the set of routes calculated by the optimisation engine.

Thus, the optimisation engine aims to vary the tasking orders of the vehicles within predefined limits, to provide optimal (or near optimal) telecommunication network coverage and throughput based on the operational need. The invention

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makes use of an optimisation engine in the form of an optimisation algorithm or behaviour engine that takes into account assets which can potentially provide communications. It will be understood by those skilled in the art that the
5 terms "optimisation", "optimal" and the like do not necessarily refer to globally most-preferable scenarios, but rather refer to scenarios that are determined to be optimal by operation of an optimisation procedure. As is well known, such optimisation procedures can in practice identify
10 as optimal scenarios that are locally but not globally optimal.

The optimisation engine may utilise any appropriate optimisation algorithm, for example evolutionary algorithms, Tabu, or simulated annealing.

15 The network configuration database may include details of network routing algorithm(s) used in the network. The network configuration database may include details of the locations of fixed nodes in the network. The network configuration database may include details of the locations
20 of the pluralities of vehicles at one or more moments in time. The network configuration database may include details of network characteristics of the telecommunications devices included in the vehicles, for example the bandwidth and/or range of the devices. It may also store achievable
25 topologies, in view of the acceptable variations in the routes of the vehicles.

It may be that the acceptable variation in the route is constrained by an operational limitation of the vehicle, for example one or more limitation selected from the group
30 consisting: of available fuel, available energy, available

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processing power, available memory, operational constraints, performance envelope, timescales, and type of communications capability provided.

5 The vehicles that include a telecommunications device may be aircraft, land vehicles, sea vehicles, space vehicles, or a combination of two or more of those types of vehicles. In the case of an aircraft, the vehicle may be manned or unmanned.

10 The assets database may include for example predicted geographic locations of the vehicles, scheduled departure and arrival times, and/or predicted velocities. The assets database may include for example acceptable variations in geographic locations of the vehicles, scheduled departure and arrival times, and/or predicted velocities.

15 The expected network loading data contained in the IER database may include data relating to the expected network loading requirements of a mobile operations team.

20 The tasking-order dispatcher may be configured to dispatch the tasking orders to the vehicles electronically, for example over a telecommunications link.

The present invention provides, in a second aspect, a method of controlling a telecommunications network, the method comprising:

- 25 (1) receiving data concerning the configuration of the telecommunications network;
- (2) receiving data concerning expected future telecommunications loads in a geographic area;
- (3) receiving data concerning planned movements of a plurality of vehicles in the geographic area, each
30 vehicle including a telecommunications device and

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having a planned route from a first location to a second location, and data concerning acceptable variation in said route; and

- 5 (4) optimising the availability of telecommunication connectivity in the geographic area by altering the planned route of at least one of the vehicles within the acceptable variation of that route.

The method is carried out using electronic hardware, for example the apparatus described above in relation to the first aspect of the invention. The data received concerning future telecommunications loads may include data concerning present telecommunications loads. The data may include network statistics, for example link loading, error ratio, and/or delay.

15 The optimisation of the availability of telecommunications activity may comprise the steps of (a) calculating a set of routes for the vehicles that optimises the availability of telecommunication connectivity in the geographic area, and (b) instructing the vehicles to follow those routes.

The data received concerning future telecommunications loads may include data concerning future telecommunications needs of vehicles or individuals operating in the geographic area.

25 The method may include the step of calculating expected network loads from the data concerning the future telecommunications needs and the data concerning present telecommunications loads.

The method may include the step of updating one or more databases containing expected information exchange

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requirements and/or node locations, in view of the data received concerning future telecommunications loads.

It may be that the optimisation of the availability of telecommunication connectivity in the geographic area is
5 achieved by optimisation of the network topology and node locations in view of all relevant constraints. Thus, the capabilities of the various assets may be considered, along with the loading, to calculate the best layout to achieve the anticipated IERs. That includes predicting link
10 behaviour, so terrain and weather conditions may be relevant; thus, the data concerning future telecommunications loads may include meteorological and/or geographic data.

The planned route of at least one of the vehicles may
15 be altered by dispatching updated tasking orders that implement the altered route.

The method may include repeating steps (1) to (3) of the method. The method may include the step of comparing the benefit of implementing the route alteration with the
20 cost of changing the orders of the vehicle. Thus, the method may take into account the "cost" of changing the orders and so will not necessarily recommend change.

It will of course be appreciated that features described in relation to one aspect of the present invention
25 may be incorporated into other aspects of the present invention. For example, the method of the invention may incorporate any of the features described with reference to the apparatus of the invention and *vice versa*.

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Description of the Drawings

Embodiments of the present invention will now be described by way of example only with reference to the
5 accompanying schematic drawings of which:

Figure 1 shows network apparatus employed in a first example embodiment of the invention;

10 Figure 2 is a flow chart showing the steps of a method of operating the apparatus of Fig. 1 according to the first embodiment of the invention; and

Figure 3 is a schematic illustration of a mission scenario in which the apparatus of Fig. 1 and the method of Fig. 2 are employed.

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Detailed Description

In a first example embodiment of the invention, network apparatus 10 includes (Fig. 1) a network configuration
20 database 20, an assets database 30, an expected IER database 40, an optimiser/behaviour engine 50 and a tasking order dispatcher 60. The apparatus 10 is connected to a target network 70, which includes mobile telecommunications assets, by which is meant devices that are able to act as nodes in
25 the target network 70. The target network 70 includes telecommunications assets that are carried by an operations team, who are to travel through a geographical area having poor telecommunications network coverage. The target network 70 also includes telecommunications assets mounted
30 on vehicles that are tasked with orders not related to telecommunications needs (including freight transport

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vehicles tasked with orders relating to the movement of freight across the geographic area), as well as telecommunications assets mounted on UAVs and other platforms dedicated to carrying the assets.

5 The network configuration database 20 is a standard database that stores the configuration of the network 70.

 The assets database 30 is a database that stores tasking orders for mobile assets that form part of the network 70. The assets database 30 also stores parameters
10 defining the extent to which the tasking orders for each mobile asset may be varied.

 The expected IER database 40 stores details of expected future telecommunications need, and hence of the network loading expected in the future.

15 The optimiser/behaviour engine 50 is configured to determine the optimal route for each mobile asset, having regard to the network configuration stored in the network configuration database 20, the tasking orders and related parameters stored in the assets database 30, and the details
20 of expected future telecommunications need stored in the expected IER database 40. In the present example, the well-known optimisation technique of simulated annealing is used to calculate the optimal routes. In alternative embodiments, other optimisation techniques are used, e.g.
25 evolutionary algorithms or Tabu search. It is a feature of these techniques that they allow the inclusion of constraints and discontinuous penalty functions. In the context of behavioural engines, they are available commercially (e.g. Erudine) and can run on very modest
30 hardware, and have sub-second reaction times and thousands

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of "rules" equivalent, as well as highly effective "tacit" knowledge capture techniques.

The tasking order dispatcher 60 is configured to dispatch tasking orders to the mobile assets. The tasking
5 orders, when followed by the mobile assets, implement the optimal routes calculated by the behaviour engine 50.

Operation of the apparatus 10 is as follows (Fig. 2):

Step 120: statistics relating to the present state of the network 70 (e.g. link loading, error ratio, delay etc.)
10 are gathered and stored in the network configuration database 20.

Step 130: details of current and future tasking orders (or changes thereto) are stored in the assets database 30.

Step 140: details of current and expected future
15 telecommunications needs, including the expected needs of the operations team (or changes thereto) are stored in the expected IER database 40.

Step 150: the network statistics stored in the network configuration database 20 are compared with anticipated
20 loads calculated from the details of current and expected future telecommunications needs stored in the expected IER database 40, and from that information future network usage is predicted. Thus, the expected telecommunications needs, and hence the predicted loads on different parts of the
25 network 70, are sanity-checked against the existing loads, and consequently the predicted load is adapted. The network configuration database 20, assets database 30, and expected IER database 40 are updated in view of that predicted usage, including the expected IER and node locations.

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Step 160: an optimisation of a model of the future topology and node locations of the network 70 is calculated, taking into account all known constraints, including the tasking orders and allowable variations therein for the various assets and the predicted loading of the network 70. The optimisation also takes into account terrain and weather conditions, which can affect the behaviour of links in the network 70. The optimisation aims to calculate the best layout to achieve the predicted IERs.

Step 170: dispatch of updated tasking orders to mobile assets in the network 70 by the tasking order dispatcher 60, so that the desired topology is achieved.

Steps 120 to 170 are repeated continuously. However, note that the system will take account of the "cost" of changing the tasking orders, and so will not necessarily recommend change. A good trade-off between the cost of change and the increase in value of the new approach will be assessed in the optimiser 50 (it can for example be treated as another constraint in the optimiser).

A hypothetical mission scenario (Fig. 3) will now be described, as an example to illustrate operation of the apparatus and method.

A network is deployed in a region. However, there are whole areas where communication is impossible. Three communication UAVs are the only dedicated assets available for deployment to cover the affected region. Due to maintenance and handover between UAVs, typically only one UAV, in Fig. 3 the aircraft 250, is in the air at a given time. Consequently, groups that go out into the region

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frequently do not get reliable communications and therefore arrive in the wrong place at the wrong time.

In this example, an operations team 220 is travelling NE from the SW corner of the region shown in Fig. 3, in a straight line to a base 240. The UAV 250 is already tasked with operations in the NW region, and, although it heads in an ESE direction along a route 260 towards the same base 240, the radio coverage 270 of the UAV 250 only overlaps with the route of the team 220 in its latter stages.

However, the coordinator of the operation fits communications appliques to a dozen aerial vehicles that are in use fairly frequently in the area and have central automated coordination of those assets. Using automated optimisation of the network topology, as described above, the flight plans of the upgraded aerial vehicles are adjusted so that at any one time there is a network that can cope with the communications load. The vehicles are used to fill gaps in the network when no other asset can cover the region. In this case, frequently two vehicles 280, 330 are used simultaneously, as they do not have to cover for each other, as other aerial vehicles will often be able to take over before the vehicle must refuel. The net result is that continuous coverage can be maintained most of the time on the ground. This allows full situational awareness, and an ability to rapidly react to changes in circumstances with better command and control.

In this example, a transport aircraft 280 is tasked to fly E from the SW region to a base 300 in the SE region, along a direct flight path 290. However, there is considerable leeway in the timing of the flight, and plenty

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of fuel available. The optimisation engine 50 calculates an alternative route 310 for the aircraft 280, wherein the aircraft 280 first heads NE, tracking the team 220, before veering SE to complete its own mission. New tasking orders
5 are transmitted to the aircraft 280 by the tasking order dispatcher 60, instructing its pilot to take that revised route. The flight path is such that the radio coverage 320 of the communications appliqué fitted to the aircraft 280 enables the team 220 to remain in contact with the network
10 70 for most of the first half of its route 230.

A second aircraft 330 is tasked to fly in a straight line 350 WNW from the E region, towards a third base 340. The optimisation engine 50 calculates that, by delaying the take-off time of the aircraft 330, telecommunications
15 coverage can be provided to the team 220. New tasking orders are transmitted to the aircraft 330 by the tasking order dispatcher 60, its pilot alters his route accordingly, and the radio coverage 360 provided by the aircraft 330 substantially fills the gap in network connectivity that the
20 team 220 would otherwise suffer on its route 230 between the coverage of the aircraft 280 and the UAV 250.

Example embodiments of the invention thus employ a novel technique for dealing with the tasking of the movement of communications nodes, in particular communications nodes
25 on non-communications assets. The technique incorporates the control of movement (within operational constraints) of all relevant assets. By utilising this approach, the maximum effect can be squeezed from available assets. Opportunistic and DTN networks are known to be a difficult area; this

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approach is looking at the problem from a more holistic viewpoint.

The system can efficiently incorporate whatever assets are available. By taking this approach, the cost of ownership for airborne nodes may be reduced by the efficient piggy-backing of communications nodes on non-communications assets. In general, by adding some flexibility into a system, by being able to alter the planning within constraints, large gains can be expected in the ideal case. This will allow a slow introduction of airborne communications nodes which will not require an immediate large outlay for the advanced UAVs (which is unlikely to be accepted in the present economic climate). Instead, it will reuse existing platforms where possible, thereby lowering the cost of entry, although gradually it could lead to a fully UAV-based system over time.

Whilst the present invention has been described and illustrated with reference to particular embodiments, it will be appreciated by those of ordinary skill in the art that the invention lends itself to many different variations not specifically illustrated herein.

Where in the foregoing description, integers or elements are mentioned which have known, obvious or foreseeable equivalents, then such equivalents are herein incorporated as if individually set forth. Reference should be made to the claims for determining the true scope of the present invention, which should be construed so as to encompass any such equivalents. It will also be appreciated by the reader that integers or features of the invention that are described as preferable, advantageous, convenient

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or the like are optional and do not limit the scope of the independent claims. Moreover, it is to be understood that such optional integers or features, whilst of possible benefit in some embodiments of the invention, may not be
5 desirable, and may therefore be absent, in other embodiments.

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Claims

1. A network controller for controlling a telecommunications network comprising a plurality of vehicles each including a telecommunications device, the
5 network controller comprising:

a network configuration database, containing data representing the configuration of the network;

an assets database, containing for each vehicle (i) data representing planned movements of the vehicle in a
10 geographic area, the vehicle having a planned route from a first location to a second location, and (ii) data representing parameters for acceptable variation in said route;

an information exchange requirement (IER) database,
15 containing data representing expected future network loading;

an optimisation engine configured to calculate from the data stored in the network configuration database, assets database and IER database, a set of routes for the vehicles
20 that optimises, subject to the parameters for acceptable variation, the availability of the telecommunications network in the geographic area; and

a tasking-order dispatcher, configured to generate tasking orders for transmitting to the vehicles from the set
25 of routes calculated by the optimisation engine.

2. A network controller according to claim 1, in which the network configuration database includes details of the network routing algorithm(s) used in the network.

3. A network controller according to claim 1 or claim 2,
30 wherein the network configuration database includes details

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of network characteristics of the telecommunications devices included in the vehicles.

4. A network controller according to any preceding claim, wherein the assets database includes predicted geographic
5 locations of the vehicles, scheduled departure and arrival times, and/or predicted velocities.

5. A network controller according to any preceding claim, wherein the assets database includes acceptable variations in geographic locations of the vehicles, scheduled departure
10 and arrival times, and/or predicted velocities.

6. A network controller according to any preceding claim, wherein the expected network loading data contained in the IER database includes data relating to the expected network loading requirements of a mobile operations team.

15 7. A network controller according to any preceding claim, in which the acceptable variation in the route is constrained by an operational limitation of the vehicle, for example one or more limitation selected from the group consisting of: available fuel, available energy, available
20 processing power, available memory, operational constraints, performance envelope, timescales, and type of communications capability provided.

8. A method of controlling a telecommunications network, the method comprising:

25 (1) receiving data concerning the configuration of the telecommunications network;

(2) receiving data concerning expected future telecommunications loads in a geographic area;

(3) receiving data concerning planned movements of a
30 plurality of vehicles in the geographic area, each vehicle including a telecommunications device and having a planned

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route from a first location to a second location, and data concerning acceptable variation in said route; and

(4) optimising the availability of telecommunication connectivity in the geographic area by altering the planned
5 route of at least one of the vehicles within the acceptable variation of that route.

9. A method as claimed in claim 8, in which the data received concerning future telecommunications loads includes data concerning present telecommunications loads.

10 10. A method as claimed in claim 9, in which the data includes network statistics, for example link loading, error ratio, and/or delay.

11. A method as claimed in any of claims 8 to 10, in which the data received concerning future telecommunications loads
15 includes data concerning future telecommunications needs of vehicles or individuals operating in the geographic area.

12. A method as claimed in any of claims 8 to 11, including the step of calculating expected network loads from the data concerning the future telecommunications needs and the data
20 concerning present telecommunications loads.

13. A method as claimed in any of claims 8 to 12, including the step of updating one or more databases containing expected information exchange requirements and/or node locations, in view of the data received concerning future
25 telecommunications loads.

14. A method as claimed in any of claims 8 to 13, in which the optimisation of the availability of telecommunication connectivity in the geographic area is achieved by optimisation of the network topology and node locations in
30 view of all relevant constraints.

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15. A method as claimed in any of claims 8 to 14, in which the planned route of at least one of the vehicles is altered by dispatching updated tasking orders that implement the altered route.

5 16. A method as claimed in any of claims 8 to 15, including repeating steps (1) to (3) of claim 8.

17. A method as claimed in any of claims 8 to 16, including the step of comparing the benefit of implementing the route alteration with the cost of changing the orders of the
10 vehicle.