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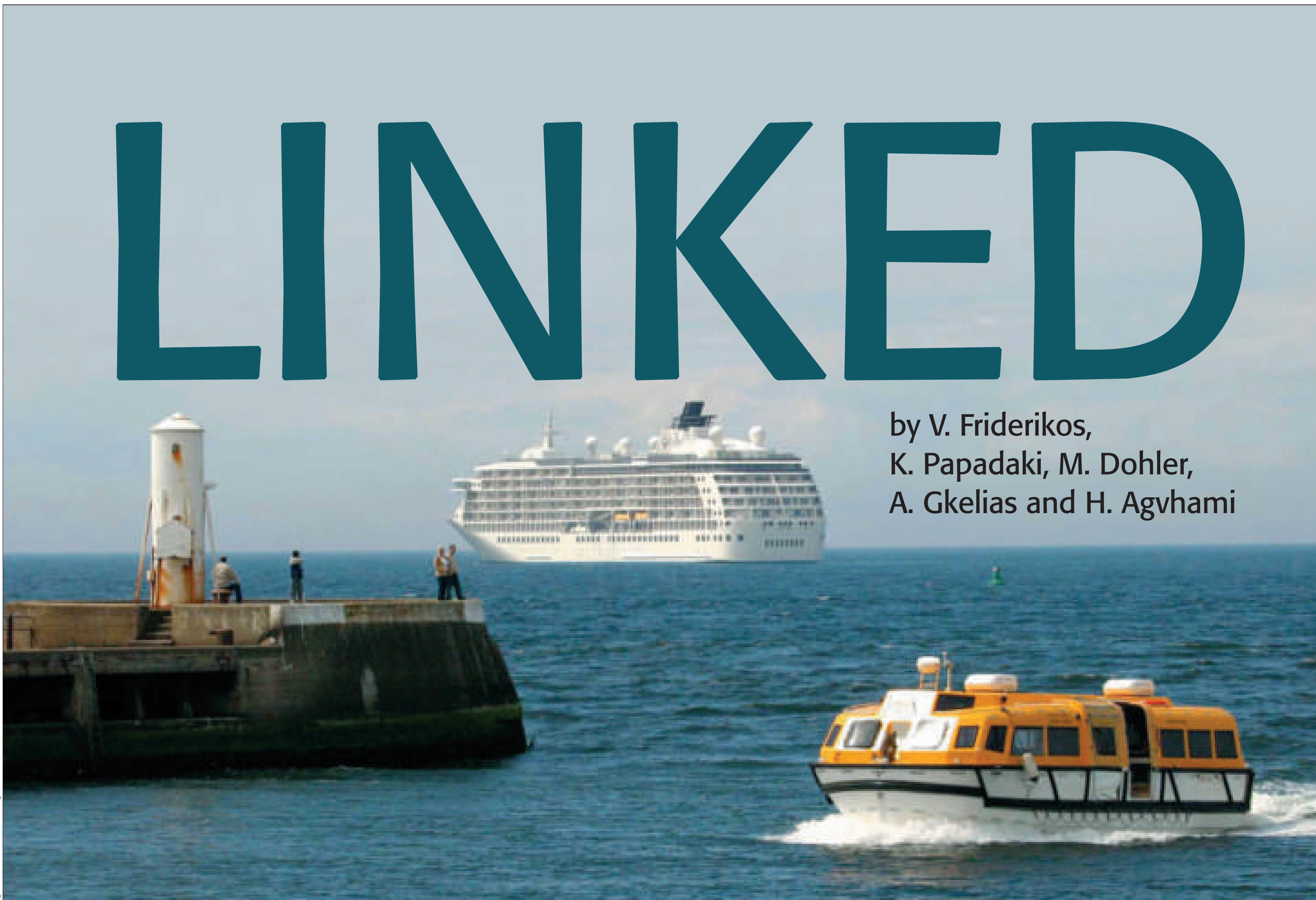

[Photo: Vismedia]

***From land to the deep sea:*** *vessels would act as relaying nodes*

## A COMBINATION OF WiMAX AND MESH NETWORKING COULD BRING BROADBAND ACCESS TO THE MEDITERRANEAN SEA WITHOUT THE HELP OF SATELLITES

After spending a few hours in Tunis exploring lively 'medinas' at the exotic realms of the Sahara, you are cruising in the middle of the Mediterranean sea towards the ancient Pompeii near Naples. You have hundreds of digital photos and small video clips that you would like to share with your friends back home. Using a combination of WiMAX and mesh networking technology, it would be possible to connect to the Internet via other vessels that act as relaying nodes to a specific shore Internet gateway point and exchange files, chat online or even take part in a video phone call.

The number of cruise passengers worldwide is anticipated to reach 22 million by 2010, with 18% of them in the Mediterranean. Currently, some of the major players in the cruise industry even provide Wi-Fi access onboard with signal backhaul through satellite connections. But it is not only passengers – crewmembers of different kind of vessels require Internet connectivity to stay in touch with their families and friends. Currently, supporting connectivity to the Internet in such environments is only possible through satellite. But although satellite communications can provide fully reliable services, they also have severe limitations in terms of uplink and downlink bandwidth, cost, spectrum availability and latency issues.

High-speed wireless broadband technology based on the IEEE 802.16 standard (also known as WiMAX) can provide the required building blocks for high throughput, large cell radius with enhanced quality of service (QoS) support. WiMAX, together with synergetic mesh networking technologies such as QoS-aware routing, can potentially provide a solution for onboard Internet broadband access without using a backhaul satellite communication system. Such a system could be implemented today even in areas where there is no fixed infrastructure.

> “This can be considered a dense network where connectivity to the Internet is almost certain”

# WATERS


*Some 220,000 vessels of more than 100 tons cross the Mediterranean each year*

## WIMAX POTENTIAL

The IEEE 802.16a technical specification was published in April 2003. The latest revision of the standard (IEEE 802.16-2004) is setting WiMAX as a wireless broadband technology with high potential[1]. The physical layer specifications of the standard use orthogonal frequency division multiplexing with a high spectral efficiency (bits per second per hertz) over ranges from two to 50km with up to 70Mbit/s in a single RF channel (channel sizes range from 1.5 to 20MHz).

However, it should be noted that in the maximum distance range only a few Mbit/s would actually be attainable (for example, using binary phase shift keying in a 5MHz channel with 1/2 coding rate, less than 2Mbit/s would be available).

Advanced topologies (such as mesh networks) and antenna techniques (such as beamforming, space-time coding or antenna diversity) can be employed to improve coverage. These advanced techniques can also be used to increase spectral efficiency, capacity, reuse, as well as average and peak throughput per RF channel. Additionally, the 802.16e specification – which is likely to appear in a stable format by 2006 – will allow seamless hand-offs between base stations, therefore providing true mobile broadband connectivity.

WiMAX can operate both in point-to-multipoint mode (providing fixed broadband wireless access) and in mesh mode. When WiMAX operates in a mesh, multi-hop wireless environment, a neighbour-aware resolution algorithm derives scheduling decisions so that different nodes can have fair access to the medium. Based on such a protocol, collision-free scheduling is possible within the extended (two or three hops away) neighbour set of each node.

Distributed scheduling is implementation-dependent; →

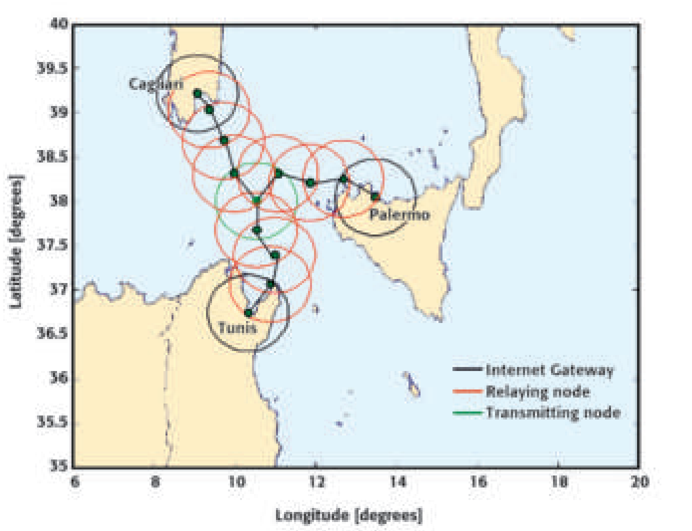


*Fig 1: A scenario of multi-hop communication with multiple possible gateways to the Internet*

therefore, different methods/schemes can be used. For such a distributed transmission coordination algorithm to operate in the mesh mode, there is a control period at the beginning of each MAC frame in which each node can periodically transmit the computed schedule to the extended neighbour set. Therefore, a new MAC layer management message has been introduced, the mesh schedule (MSCH). The role of MSCH is to distribute information about the network status to allow mesh network configuration.

In order to route traffic between a specific node to the Internet in such a multi-hop environment, an IP layer routing taking into account the QoS requirements of different flows should be supported. In that respect, an embedded QoS routing logic[2] is required to find a feasible path between the source node and the destination (Internet gateway).

Additionally, a protocol is required for a node to discover the gateway node to the Internet in a reactive or proactive manner[3]. We assume that these gateways will be on-shore stationary stations. An example of such a scenario is shown in fig 1. As can be seen from this example, the transmitting node is four hops away from three Internet gateway stations in Tunis, Cagliari and Palermo (the transmission radius for all nodes shown in the graph is 50km).

## SYNERGY BETWEEN WIMAX, GMDSS & GPS

***Digital selective calling (DSC)***. The DSC is part of the global maritime distress and safety system (GMDSS), which is an international system for marine communications. DSC's 'geographical call' function can only contact radios whose GPS interface indicates they are within a designated geographical area (the effective range of DSC is well above 300km).

***Beamforming***. This exchange of GPS information through DSC could be integrated into the MAC distributed protocol of WiMAX to perform beamforming, therefore increasing the range to specific adjacent nodes. This is shown in fig 2, where node A wishes to communicate with node F. Using information from DSC, node A and the corresponding intermediate nodes perform beamforming to selected nodes; therefore, the probability of collision with other nodes is decreasing and the effective transmission range is increasing. Note that beamforming towards a spatially adjacent ship can also be achieved by means of continuous (digital) beam-sweeping until two ships lock onto each other's signals, with the clear advantage of not needing the satellite backhaul altogether.

> **"The unpredictable network topology and high degree of mobility pose challenges for QoS routing support"**

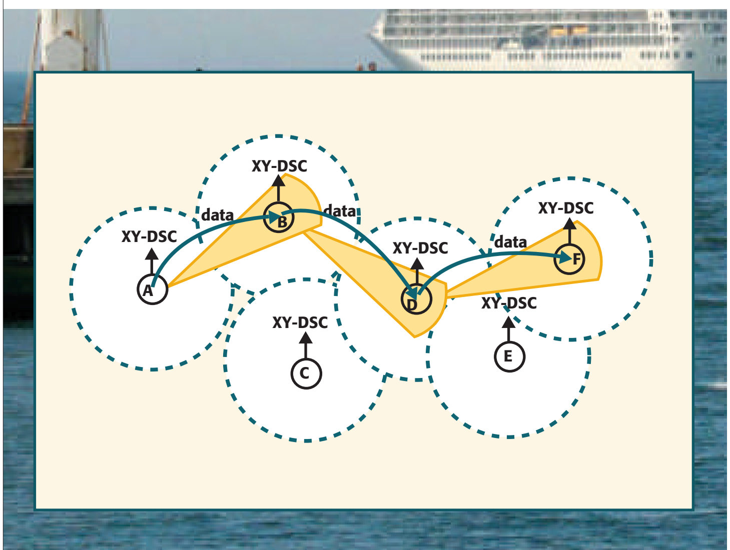


*Fig 2: Optimal relaying between vessels by broadcasting longitude/latitude information (GPS) through the digital selective calling (DSC)*

We can therefore assume that WiMAX can operate in two different modes: *omni* and *directional*. In the omni mode, each node is capable of receiving and transmitting signals in all directions (360 degrees) with gain $G \approx 0$dB. On the other hand, in the directional mode, a node can point its beam towards a specific direction with gain $G_d$ (where $G_d > G$). Because of the higher gain, nodes in directional mode have a greater range in comparison with the omni mode. This, as we demonstrate below, can – but not necessarily does! – increase the probability of connectivity in an environment of low-vessel density. Finally, it should be again emphasised that the attainable data rates with distance range extension will be in the order of few Mbit/s.

## ANALYSIS OF CONNECTIVITY

It is estimated that about 220,000 vessels of more than 100 tons cross the Mediterranean each year. Daily, an estimated 2000 vessels cruise the Mediterranean, of which 250/300 are oil tankers. For simplicity, we will assume that N vessels are uniformly distributed in the Mediterranean basin of area A, which can be considered as a worst-case bound for required connectivity in relation to the more realistic scenario of specific traffic routes.

***Omni & directional WiMAX modes***. The node density based on the above assumptions is $\rho = N/A$. In a node's coverage area of $A_0 = \pi \cdot r_0^2$, where $r_0$ is the communication radius in omni mode, there will be in average $\rho \cdot A_0$ ships. This leads to an average degree of connectivity of $\langle C \rangle = N \cdot A_0 / A - 1$. In the directional mode, we assume first that the ships have a fixed antenna array with M elements without the possibility of beam-steering. The gain due to fixed beamforming is approximately M which, with a path loss coefficient of $\gamma$, leads to a range extension of $r_M = r_0 \cdot \sqrt[\gamma]{M}$. At the same time, the reduced beamwidth leads to a coverage area of $A_M = \pi \cdot r_M^2 / M$, and hence to an average number of ships in that area of

$\rho \cdot r_0^2 M^{2/\gamma-1}$ ships. Clearly, with $\gamma>2$, fixed beamforming does not yield any gains. If, however, any of the two above introduced adaptive beamforming methods is used, then the average connectivity can be shown to be $\langle C\rangle=\rho \cdot \pi \cdot r^2 M^{2/\gamma}-1$.

***Performance example.*** Given the area of the Mediterranean of $A \approx 2.5$million km$^2$, N=2000, and a range of $r_0$=50km, the average degree of connectivity is $\langle C\rangle$=5.2. This can be considered as a dense network where connectivity to the Internet can be assumed to be almost certain. Fig 3 shows the calculated average degree of connectivity in the Mediterranean for different ranges of transmission radius and number of nodes. The graph also depicts the plane corresponding to minimum degree of connectivity equal to 1.

These results clearly demonstrate that the mesh mode of WiMAX can potentially offer broadband wireless access truly anywhere at anytime. The analysis was based on the assumption of a uniform distribution of nodes. In reality, vessels follow specific shipping routes and therefore their spatial distribution cannot be considered as uniform in the whole area. Generally speaking, such non-uniform distribution can achieve even higher expected degrees of connectivity.

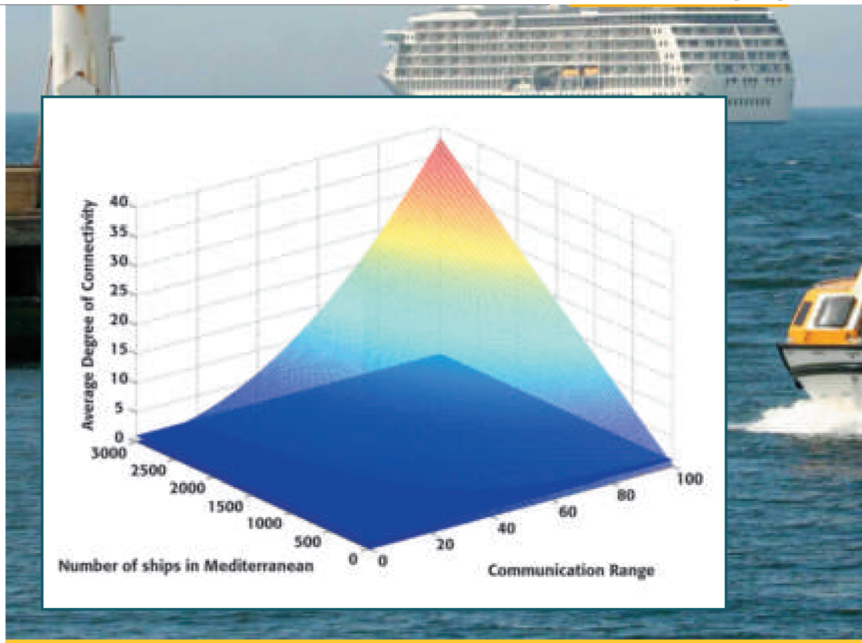


*Fig 3: Average degree of connectivity Vs communication radius and number of ships, together with the plane of* $\langle C\rangle = 1$

## JUST THE BEGINNING

The emergence of the 802.16 standard will create a complete new arena for innovation concerning flexible broadband connectivity to the Internet. Wide adoption of broadband wireless access and mesh networking can eventually provide ubiquitous connectivity to the Internet at anytime and anywhere.

Using a simple case study of a possible future application, we have shown that connectivity to the Internet in the Mediterranean is possible, without using an expensive, low-bandwidth and high-latency satellite backhaul. Regardless of the commercial impact that such a proposal might have for future marine communications, this example is just one of a myriad of possible applications for mesh, multi-hop wireless networks supporting connectivity to the Internet.

However, there are still many fundamental research challenges in this field. One critical issue is how to stimulate cooperation between the nodes in order to avoid selfishness, i.e. nodes that are not willing to forward packets for the benefit of other nodes. This issue is closely related to the aspects of security and privacy in such networks. In the Mediterranean Sea case, for example, it is possible that vessels avoid sending traffic through multi-hop routes due to security considerations. Thus, to extend mesh-based networks into real-world use, there is a clear research need to first resolve the security aspects of such self-organised systems.

An additional important issue to be addressed is the optimisation of MAC protocols so that they take into account directionality of the transmission and allow efficient use of the network resources. The unpredictable network topology, the high degree of mobility and intermittent connections pose challenges for QoS routing support. In that respect, very little work has been done on the interactions between QoS routing, different distributed and delay-constraint MAC protocols[4].

Finally, we cannot but add that the behaviour of higher-layer protocols such as TCP and the performance of real-time oriented protocols such as RTP (real-time protocol) and RTSP (real-time streaming protocol) are still to be evaluated in such largescale, spatially distributed multi-hop networks. ■

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