Information Raining for Mobile Hotspots in 4G Wireless Networks

(invited paper)

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***Abstract*—A system architecture is proposed to support mobile hotspots. The proposed architecture uses multiple repeaters to relay signals from access routers to vehicles and vice versa. Erasure codes are used in the access router to decompose data packets into fixed size fragments. The fragments are then disseminated to the vehicle through the repeaters. The original packet is reconstructed in the vehicle station by consolidating the detected fragments. We call this approach information raining and show how it can be used to provide high throughput to highly mobile users. We show that the proposed system does not need handoff. We also design a new mobile IP architecture that can be applied to batches of IP addresses.**

I. INTRODUCTION

Recently we witness proliferation of hotspots in places such as coffee shops, shopping malls, airports, hotels, convention centers, and so on. An apparent question is whether it is possible to extend hotspot technology to mobile users. In this paper, we present challenges on achieving such a goal and propose an open architecture for mobile hotspots.

Cellular systems and wireless local area networks (WLANs) are the two major wireless technologies. The next generation wireless networks should consolidate cellular systems and WLANs. If such an integration is achieved, users can move between cellular systems and WLANs without service interruption. Figure 1 illustrates the bandwidth versus mobility for cellular and WLAN technologies. As seen these two technologies have different bandwidth-mobility requirements and the integration may not be straightforward.

There are a few challenges in designing an architecture that can support mobile hotspots. The first problem is the high velocity of vehicles. The current cellular systems have not been designed to support the speeds beyond 250 km/h. The second challenge arises from the fact that a large number of users travel together. Therefore, a large bandwidth should be delivered to the vehicle. Current technologies can only support high bandwidth for stationary or nomadic users. Mobile users cannot enjoy the same bandwidth as the nomadic users.

By using orthogonal frequency division multiplexing (OFDM), multiple-input multiple-output (MIMO), adaptive modulation and coding (AMD), ultra wideband (UWB), etc, it is possible to achieve bit rates in the order of 100 Mbit/s for fast mobile units, however the cell size will be much smaller than the current cellular systems. The small cell size mandates frequent hand-offs. The signalling load of hand-off can be a bottleneck in micro-cellular systems.

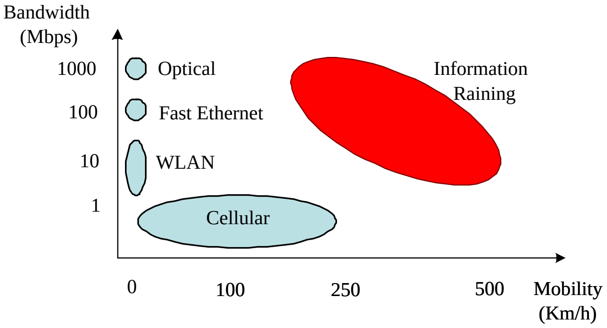

Fig. 1. Mobility versus bandwidth plot.

In this paper, we design a system architecture that supports high bandwidth for mobile users travelling at very high speed. Examples of such users are the passengers of *maglev* (magnetic levitation) trains travelling at 450 km/h. We propose an architecture that allows the passengers of such trains to connect to the Internet while travelling on their route. A similar architecture can be used to support high bandwidth wireless connectivity to subway trains in urban areas and in mining industry.

II. SYSTEM ARCHITECTURE

In this section, we propose a new architecture for next generation (4G) vehicular cellular systems. We notice that a single wireless link connecting the base station to the mobile unit cannot satisfy both high bandwidth and high mobility. We propose to break this link into three links as denoted in Figure 2. The figure illustrates the functional units that are used in this paper. We will discuss these elements in the sequel.

We can locate in Figure 2 an access network connected to the Internet via a *gateway router* and to the mobile units via several *access routers*. The access network can be a wired network that is built to extend services to mobile units. An extension of mobile IP protocol is necessary to handle mobility management. We will discuss this extension in an ensuing section.

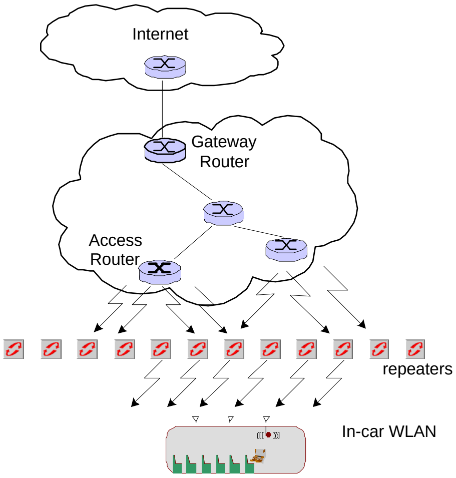

Fig. 2. The proposed multiple-link system architecture.

Figure 2 also illustrates a number of *repeaters*. Repeaters are simple units, which are located along the route of the vehicle and relay packets from the access router to the vehicle and vice versa. These repeaters can be mounted on lamp posts in metropolitan area, placed on the ceiling of subway tunnels, or located along train tracks. The repeaters may also be solar/wind powered to reduce the energy cost. The repeaters create a mesh/star network that connects to access routers. The link between the access router and the repeaters may use ad hoc networks or *broadband wireless access* (BWA) as suggested by IEEE802.16, or simply a wired optical fiber connection. Since repeaters are stationary units, a high bandwidth wireless connection between the access point and the repeater is a viable solution. Note that multi-hop wireless networks are also applicable to this paradigm. Repeaters create micro-cells and can use licensed or license-exempt spectrum to communicate to the vehicle. Repeaters exploit close spatial distance and line-of-sight to burst a large number of packets to the vehicle.

Today, most of the mobile terminals are WiFi-enabled. Passengers locate an *in-car* WLAN inside the vehicle and use their terminal in a stationary/nomadic situation. Therefore, users will not need any adjustment to their wireless units. This link builds the network section inside the vehicle.

The in-car WLAN is connected to a *vehicle station* (VS) (not shown in Figure 2) that is responsible for connection to the outside world through a number of antennas mounted on the exterior of the vehicle. By using multiple antennas, we accommodate spatial diversity in the proposed solution; therefore, reliable transmission can be achieved. The set of the antennas and the repeaters also creates a MIMO channel that may be optimized to increase the total throughput to/from the vehicle [1].

III. INFORMATION RAINING

We discussed earlier that to achieve high bandwidth it is necessary to maintain close distance between transmitter and receiver in a wireless channel. The proposed architecture in the previous section achieves this objective by placing short-range repeaters along route of the vehicle. However, mobility introduces a problem in this setting: a highly mobile vehicle will soon move away from the repeater and a handoff to a new repeater is necessary to maintain service connectivity. The conventional handoff schemes cannot produce a viable solution; the signalling load is prohibitive in this case. In this section, we introduce a new approach to handle these shortcomings.

To solve the handoff problem inherent to all highly mobile vehicles, we introduce the concept of *information raining*. In this approach, *erasure coding* is used to introduce redundancy for reliable transmission of data packets. Then, each encoded data packet is decomposed into a number of fragments. The fragments are transmitted to the repeaters that are in the vicinity of the vehicle through the backhaul network and are “rained” upon the vehicle. Each antenna on the vehicle receives a number of segments and sends them to the VS. When a sufficient number of segments is collected at the VS, the original data can be reconstructed [2]. Because of erasure coding, if a small number of fragments are lost, the packet can still be recovered. We call this approach information raining where data fragments correspond to rain drops and antennas to buckets.

The vehicle periodically transmits a beacon signal to inform its presence in the vicinity of repeaters. The beacon signal awakens the repeaters and can be used to locate the vehicle along the route. The repeaters then communicate to the access router and request fragments. The access router distributes the data fragments among the awakened repeaters, which are then relayed to the air interface. In this approach, we observe that all repeaters in the vicinity of the vehicle can become active and participate in data relaying.

We propose two versions of the information raining. In the first approach, active repeaters transmit their fragments with constant power to the air interface. We let each antenna tune independently to a repeater that has the best channel conditions. This approach is a distributed case at which no information is communicated among the antennas. Therefore, multiple antennas can tune to the same repeater and receive redundant fragments. We call this case *distributed information raining* (DIF).

Repeaters can also be selected by *centralized information raining* (CIF). In CIF, all channel conditions are communicated to the VS. The VS locates the best repeater-antenna pair and informs each antenna of the repeater to which that antenna should be tuned. The VS also sends an activation signal to the corresponding repeater and sets the transmit power level in that repeater. In this approach, the repeaters, not chosen by the VS, should refrain from sending their fragments. If the data is not reconstructed in this round, the cycle is repeated and fragments in other repeaters are sought by the VS. If the data packet is reconstructed, the VS transmits a “flush” signal that removes the remaining fragments belonging to the reconstructed packet from the adjacent repeaters. CIF achieves a higher throughput than DIF [1].

Information raining removes the need for handoff in our micro-cellular system. Since the vehicle is always battered with data fragments, there is no need for handoff between neighboring repeaters. Handoff is only necessary when the vehicle moves between the boundaries of two access routers. However, information raining can also reduce the handoff load in such cases. We assume that the repeaters at the boundary of the regions controlled by two access routers can be controlled by both access routers. Therefore, both access routers can transmit their fragments through a number of common repeaters. The repeaters again relay these fragments to air interface regardless of which access router was responsible for the fragment. Because during the handoff the vehicle can receive data from both access routers, the handoff process is very smooth.

As explained earlier the beacon signal awakens a number of repeaters in the vicinity of the mobile vehicle. We visualize this phenomenon by defining a cell centered at the vehicle. The cell moves with the vehicle and meets and leaves the repeaters along its route. If the beacon signal is strong, it can activate a large number of repeaters. A larger number of repeaters can potentially achieve a higher throughput to/from the vehicle. Therefore, by changing the strength of the beacon signal we can increase the cell size and the throughput. We define this ability as *cell breathing*. By changing the cell size, the vehicle can control the throughput and the level of interference.

IV. EXTENSION OF MOBILE IP

Mobile users can be supported in an IP network using the *mobile IP* protocol. Mobile IP consists of three elements: *home agent*, *foreign agent*, and *mobile host*. The mobile host arriving at the domain of a foreign agent receives a temporary address, called the *care-of address* and registers this address with the home agent. All packets destined to the mobile host are intercepted by the home agent and tunnelled to the foreign agent and then to the mobile host. As the mobile host moves to the domain of a new foreign host the care-of address should be renewed and the registration with the home agent should be performed. Since all mobile hosts located in a vehicle change their care-of address simultaneously, a huge signalling load can be expected if the current mobile IP protocol is employed. In the sequel, we will propose a new mobile IP protocol to handle this shortcoming.

We propose a two-layer binding procedure to extend mobile IP to support batch IPs. We first note that the care-of address should be the address of the gateway router in Figure 2. In the gateway router, we should however maintain a binding between the *vehicle IP address* and the terminal IP address. Figure 3 illustrates the mobile IP binding in the system.

When a mobile host joins an in-car WLAN, it receives the vehicle IP to which it is attached and a gateway IP that it uses as a care-of address. The mobile host then registers this care-of address with its home agent. The vehicle registers this host with the gateway router that it uses as the point of attachment to the Internet. The gateway router then creates a new entry in its binding table and registers the host IP address along with the vehicle IP and the access router IP to which the vehicle is connected. The vehicle IP address acts as an IP container that holds multiple host IP addresses. The gateway registers one container for each vehicle. It is obvious that the gateway can register multiple containers corresponding to several vehicles.

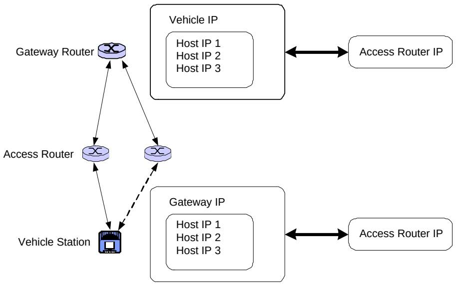

Fig. 3. The extended mobile IP binding process.

A similar approach is used in the vehicle station. The vehicle station holds a container for each gateway that it uses. Each gateway container holds the host IP address of all users that use the care-of address of that gateway. Note that it is possible to maintain multiple gateway IP addresses to allow load balancing inside the network and to avoid the bottleneck problem induced by the application of a single gateway.

When the vehicle moves between two access routers, the vehicle registers the address of its new access router with all gateways that it is using. Since the gateway address does not change for the hosts inside the vehicle, registration with the home agent of the mobile host is not necessary. When the mobile host leaves the vehicle, the care-of address is redeemed and re-registration with the home agent is needed.

V. CONCLUSION

We have proposed a new system architecture for next generation wireless networks. The proposed architecture uses a number of simple wireless units that are located along the highways or train tracks and are used as the relay elements to the vehicle. An erasure code decomposes data packets into multiple fixed size fragment. These fragments are then rained upon the vehicle from closely located repeaters. The vehicle uses multiple antennas to acquire the fragments. Detected fragments are then forwarded to the vehicle station and consolidated to reconstruct the transmitted packet. Finally, the in-car WLAN sends the data packet to the mobile host. We have called this method information raining and presented its distributed and centralized versions. We have argued that the proposed method does not require handoff among repeater. Handoff is only required between access routers; this handoff is very smooth. We have also extended mobile IP to support mobile hotspots.

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