ECONOMICS, ARCHITECTURE,
STANDARDS, AND CHALLENGES

Broadband Wireless Relay Stations

Cambise Homayounfar
Founder and CEO

PHYBIT, INC.
MARCH 2008

Contents

Broadband Wireless Relay Stations

A relay station (RS) is a radio system that helps to improve coverage and capacity of a base station (BS). Relay station has other names such as repeater, or multi-hop station. Networks that use relay stations are sometimes called cooperative networks.

Mobile operators can connect an RS to a BS by wire, by optical cable. It can also be connected by a radio link.

What is a Relay Station?

A relay station (RS) is a radio system that helps to improve coverage and capacity of a base station (BS). Relay station has other names such as repeater, or multi-hop station. Networks that use relay stations are sometimes called cooperative networks.

Mobile operators can connect an RS to a BS by wire, by optical cable. It can also be connected by a radio link.

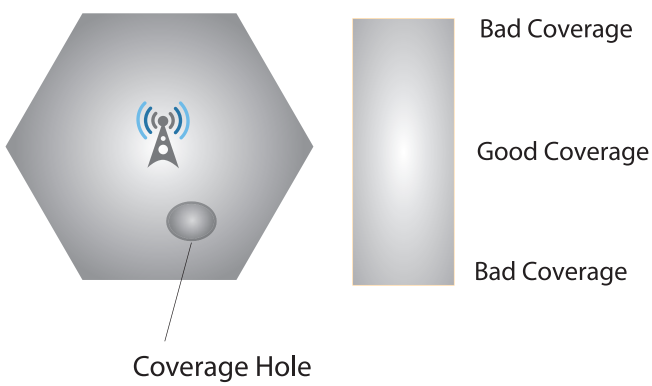

Figure 1. Illustration of Coverage Hole

Who Needs RS?

The technical reason to deploy RS is to eliminate coverage holes in a cell. A coverage hole is an area in the cell where mobile phones cannot catch a signal from the base station. When can this happen? It happens when tall buildings obstruct the signal from base stations. It also happens in underground trains. The same situation can happen for wireless LAN terminals. Mobile operators use software tools and measurement instruments to find out where these coverage holes are. Then they must do something about them. The use of RS is one option to eliminate coverage holes.

Possible RS Locations

Another place where RS can help is near the edge of the cell. When mobiles are far, they naturally receive weaker signals from base stations. For voice services, handoff helps to keep the subscribers connected. But for wireless data, throughput in Mbps becomes very low.

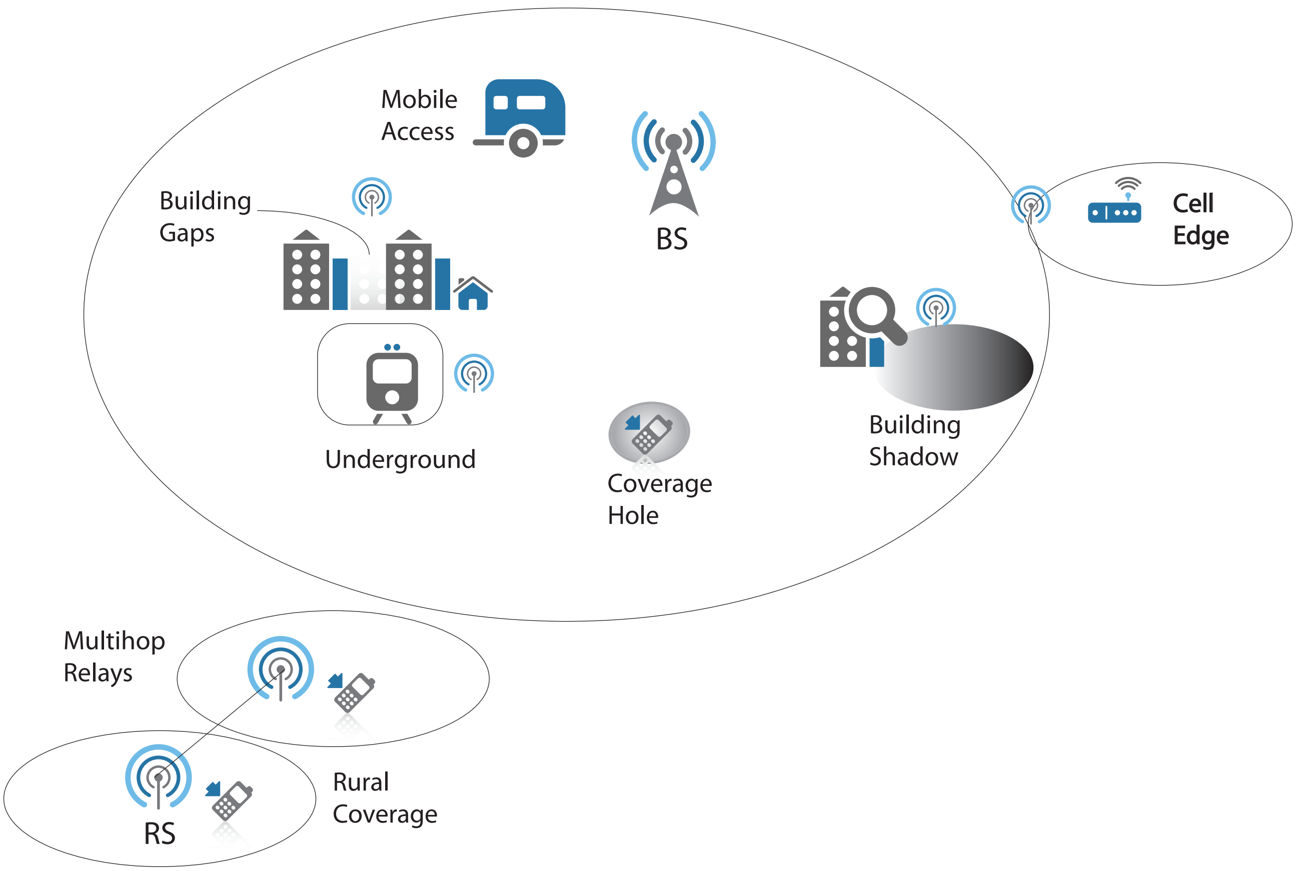

Figure 2: Possible RS Deployment Locations

Economics of RS

Economic models for RS pose and answer a simple question: how much should an RS cost in order to be a profitable investment?

From the mobile operator's viewpoint, the main question about RS is how it can improve the profitability of the network. In other words, what is the Return on Investment (ROI) for using relay stations?

The answer to this question depends on whether the operator wants to make a brand-new network, or upgrade an existing network. As more people subscribe to mobile services, mobile operators upgrade their network. The decision about how to upgrade is an economic decision and the cost of upgrade is a significant issue for mobile operators.

These days, very few brand-new networks are being made. Most operators focus on upgrading their current networks. This means that the sites for base-stations are already chosen. To upgrade the network, new equipment are installed and transmission lines are upgraded.

RS Cost Analysis

Experts at the Royal Institute of Technology in Stockholm have developed and published simple and useful economic models for cellular networks [2].

The works of Bogdan Timus are particularly useful for relay-based networks [3 and 4]. He considers a network with only BS equipment as a reference. The cost for such a network is proportional to the density of base stations in the service area. This makes sense and is simply:

$$C_{ref} = c_b . \lambda_{b0} \quad (1)$$

Where C_{ref} is the cost of the reference network, c_b is a onstant of proportionality, and λ_{b0} is the density of base stations (without relays) per km^2.

Now, a mixed network that includes both base stations and relay stations will have a different cost, C_{mix}, such that:

$$C_{mix} = c_r . \lambda_r + c_b . \lambda_b \quad (2)$$

Here λ_b is the density of base stations per km^2 with relays, λ_r is the density of relay stations, and c_r is the constant for relay station costing.

It is clear that the mobile operator would like $C_{mix} < C_{ref}$. This means:

$$C_{mix}/C_{ref} = (c_r . \lambda_r + c_b . \lambda_b)/c_b . \lambda_{b0} < 1 \quad (3)$$

The Challenges of RS Costing

So for an operator to decide to use relay stations, the condition in equation 3 must be satisfied. Operators know the cost of base stations from their equipment suppliers, so it is easy to calculate c_b and c_r.

The determination of the density of base stations λ_{b0}, λ_b or λ_r is not so simple. These parameters depend on:

- How much traffic subscribers generate
- The radio propagation properties in the cell
- How much interference exists in each cell,
- What kind of multiple access scheme is used,
- How much radio bandwidth is available for each cell, and
- How much throughput is assigned to an average subscriber.

The service area makes a big difference. The densities for highly populated cities like Tokyo are obviously very different to rural areas. Even in cities, wether the cells are located in a neighborhood with tall buildings, e.g. certain areas of Shinjuku, or they are in residential sections, leads to dramatic differences in the benefits of relay stations.

Practical Problems

Timus considers many of the above challenges. He concludes that a relay station ought to cost from 3% to 9% of base stations in order to make economic sense. One disadvantage of his analysis is that he measures cell capacity by using Shannon's formula:

$$R = W \log_2(1 + SIR) \qquad (4)$$

Where R is bit-rate achievable by a subscriber, W is the bandwidth in Hz available for communication with the subscriber, and SIR is the linear signal-to-interference ratio.

This formula is not practical in real networks. The practical bit-rate is about 25% to 50% lower than what Shannon's capacity formula gives. This amounts to a gap of 3 to 6 dB between the SIR in equation (4) and what is actually experienced by a mobile terminal.

Nevertheless, Timus's analysis provides a reasonable estimate of how much relay stations ought to cost before operators can consider using them.

It is interesting to note that the work of Timus is basically confirmed by researchers at Darmstadt University of Technology in Germany [5]. They analyzed the cell throughput of networks with several different relay architectures and found that the best performance comes from a decode-and-forward relay with maximum cost of 6% of a base station.

The Architecture of Relay Stations

Two main points must be understood about RS. First issue is wether the BS knows about the RS. This means that if the BS needs to know nothing about RS, then the integration of RS into the service area is much simpler. No change to the BS is necessary, and there is no special signalling between RS and BS. The RS is a pure helper for the BS. In this situation, RS causes no burden for the BS. Some of the earlier cellular systems such as GSM, used this kind of RS. They were simply called repeaters. The second point is the characteristic of the RS. Two kinds are popular: Amplify-and-Forward (A&F), or Decode-and-Forward (D&F). Each has different use and D&F equipment are generally more expensive than A&F.

Cooperative Relays

An interesting set of structures for relay stations is called Cooperative Relay. The signal from a base station is picked up by several relay stations, decoded, and forwarded to the mobile station through different radio paths. This scheme has the advantage that if one path is poor, another path is likely to make up for it. The improvement of Bit Error Rate (BER) at the mobile station is called Cooperative Diversity Gain.

Wireless experts are working on three types of cooperative relays.

- Same-Signal Cooperative Relay
- Space-Time Coded Cooperative Relay
- Hybrid Cooperative Relay

Same-Signal Cooperative Relay

The same-signal cooperative relay is the simplest scheme as shown in Figure 3. Here, multiple relay stations pick-up the same signal from the base station and forward it to the mobile station.

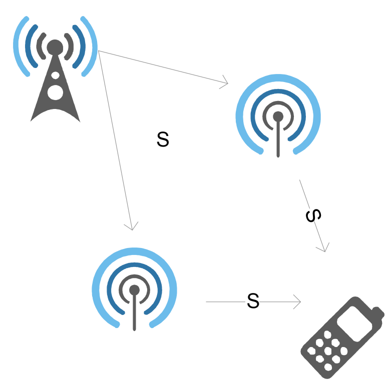

Figure 3: Same-Signal Cooperative Relays

Space-Time Coded Cooperative Relay

A slightly different scheme is to use Space-Time Block Coding (STBC) at the base station to enable the relay station to pick-up different signals, as illustrated in Figure 4. Here, the base station transmits two copies of its signal by using two antennas. The relay station can then make the most of the various received versions of the signal to improve the BER at the mobile station.

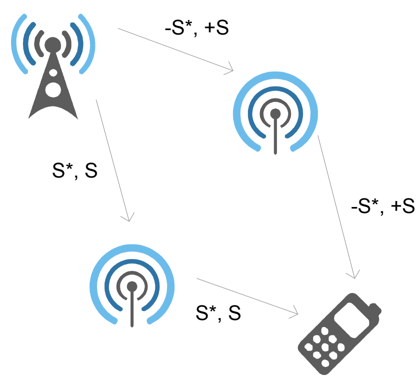

Figure 4: Space-Time Coded Cooperative Relays

Hybrid Cooperative Relay

The third scheme shown in Figure 5 is a combination of the previous two cooperative relays. It is the most complex and provides the highest gain.

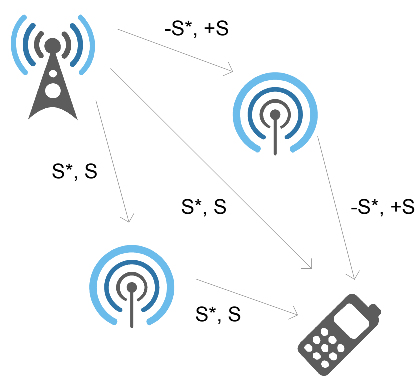

Figure 5: Hybrid Cooperative Relays

Relay Station Standards

Because of the economic advantages of RS, much research and development has taken place for the analysis and optimization of RS structures in recent years. The most comprehensive work has focused on RS for the WiMAX wireless broadband standards. In fact, the IEEE 802.16 standard committee has the Task Group assigned to relay stations and a draft standard 8021.6j is already published. Figure 6 shows how the 802.16j fits in the overall work of WiMAX standard.

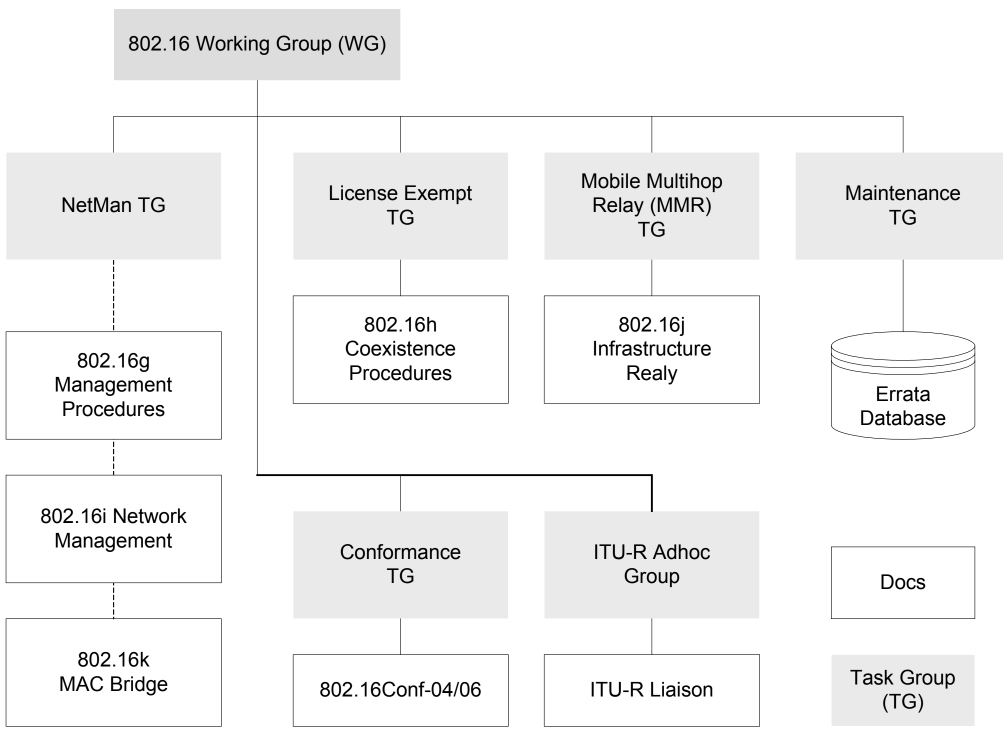

Figure 6: The Structure of WiMAX Standards and 802.16j

Next-Generation PHS (XG-PHS) standards also mention the possible use of RS. This work is for the future, but it shows that RS could become an important network element within XG-PHS.

It is clear that RS is likely to become an integral part of new standards for broadband wireless. There is no interest in RS as a pure helper of BS. This means that standards like 802.16j specify special signaling between RS and BS. They also consider signaling between RS and mobile station. At first, this extra signaling may appear as overhead for the entire network. But experts agree this overhead is worth it because RS can significantly improve the capacity, coverage, and data throughput of cellular networks.

Conclusions

The use of RS as an integral network element affects every aspect of the cellular system. Scheduling algorithms must now consider the existence of RS. These algorithms coordinate when packets are sent to mobile terminals and when they are received. Handoff between cells can now take advantage of RS and reduce the load on BS. Interference management must make sure that RS does not create extra coverage holes by destruction of the BS signal. In fact no RS is better than a bad RS.

References

1. D. C. Schultz, B. Walke, R. Pabst, T. Irnich, **Fixed and Planned Relay Based Radio Network Deployment Concepts**, in 10th Wireless World Research Forum, 27.-28, New York, USA, October 2003.
2. K. Johansson, A. Furuskar, P. Karlsson, and J. Zander, **Relation Between Base Station Characteristics and Cost Structure in Cellular Systems**, 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC, vol. 4, no. 15, pp. 2627–2631, 2004.
3. B. Timus, **Cost Analysis Issues in a Wireless Multihop Architecture with Fixed Relays**, in Proc. VTC spring, Stockholm, Sweden, June 2005.
4. B. Timus, **A Cost Model for Ad Hoc Extended Cellular Systems**, The 4th Scandinavian Workshop on Wireless Ad-hoc Networks, Stockholm, Sweden, 4-5 May, 2004.
5. C. Muller, et al., **Costs and Performance of Non-Cooperative Relay Networks**, Proceedings of the 13th European Wireless Conference, Paris, France, Apr. 2007.

PHYBIT
signalcomputing

SINGAPORE
10-10 Cendex Center
120 Lower Delta Road
Singapore 169208
PHONE: (+65) 6276-2945
FAX: (+65) 6276-2965

JAPAN
Higashi Gotanda AM Building
2-3-3 Higashi Gotanda, Shinagawa
Tokyo 141-0022 JAPAN
PHONE: +81.3.5789.7070
FAX: +81.3.5789.7071