INFOSTATIONS : A New System Model for Data and Messaging Services

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Abstract— **A new wireless system concept called *Infostations*, that can provide isolated pockets of high bandwidth connectivity, is presented for future data and messaging services. Emphasis is on an architecture that can support delay tolerant high data rate services at relatively low costs, which may account for their dramatic growth. Key issues in the design of an *Infostation* radio system are outlined while focussing on the coverage and capacity that is feasible under this concept.**

I. Introduction

Cellular systems today have evolved into an almost ubiquitous presence, bringing with them the promise (and the tyranny) of "anytime anywhere" communications. Voice messaging, email and fax are alternatives that return some control of time and place to the user, which may account for their dramatic growth. Recently, an array of isolated wireless ports called as **Infostations** have been proposed [1, 2] that can provide convenient and frequent access to high bit-rate connections. This "many-time many-where" communication is well suited to messaging and can offer a wide range of useful and economical services. Moreover, its high bit-rate can deliver information that would be impractical using a voice system, and its low cost can enable a mass market. Unlike voice systems where the payload is a bit-rate, such messaging and information systems can often tolerate significant delays. Therefore the payload of interest is often a quantity of bits rather than a bit-rate. This leads to the need for service that is frequent and predictable, rather than continuous access. Finally, while voice systems are generally equal in their uplink and downlink traffic, for data and messaging the downlink is likely to be predominant (see also [3, 4]). The above considerations lead to the issue of designing these isolated pockets (or core areas) of high bandwidth while at the same time accounting for the mobility and information (payload) requirements of users in the system.

The need to provide ubiquitous coverage in cellular systems usually is based on statistical criteria for coverage. Typically, systems are designed to provide an adequate signal-to-interference ratio (SIR) for users most of the time (e.g., $S/I > \gamma$ in 90% of locations). As a result, many locations (typically at the core of the cells) may provide a channel quality that exceeds this criterion, sometimes by a significant margin. Current systems reduce this "excess quality" through power control, or treat these core areas as a grid of overlaid microcells with reduced channel-reuse distance. Another way to capture this excess capacity would be to increase the data rate, while using the same channel bandwidth. One example of such a utilization could be to switch to a higher order modulation scheme in these core areas. While there has been little incentive for this approach in voice-only systems, messaging applications may justify future consideration of this possibility. A simpler alternative would be to use a portion of the available spectrum to provide high bit-rate services in these core locations, using a separate radio and channel. Figure 1 illustrates such core areas which could be used to deliver large files quickly with high spectral efficiency and low cost.

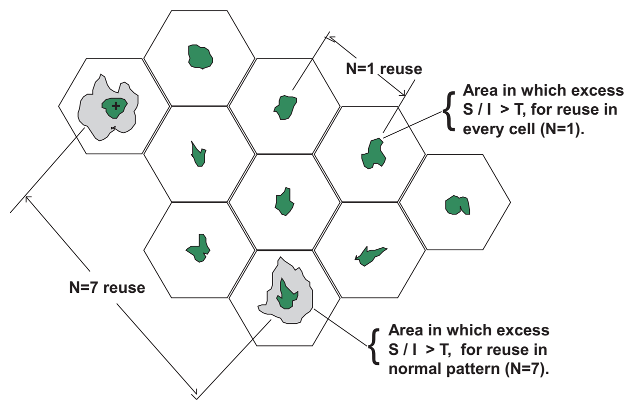

Fig. 1. Core areas in which excess capacity allows information transfer at a higher rate

As was pointed out in [1, 2] and [4], these pockets of high bandwidth connectivity could be spaced along roadways, in building entrances, at airports and in other predictable, accessible locations. In keeping with the "fast food" paradigm, such access options were characterized in [1, 2] as being "drive-through, walk-through and sit-through" with the range of an *Infostation's* coverage being a few hundred feet or less. With proper separations, all *Infostations* could share the same "channel" thereby providing transmission rates that could exceed a megabit/second, allowing significant transfer of information (e.g. fax, voice messages and large data files) to take place in a few seconds. A pictorial representation of *Infostations* providing various high bit-rate services is shown in Figure 2.

Infostations would be relatively simple devices and might be organized in different ways (see Figure 3). Individual *Infostations* on highways, streets and in airports, for exam-

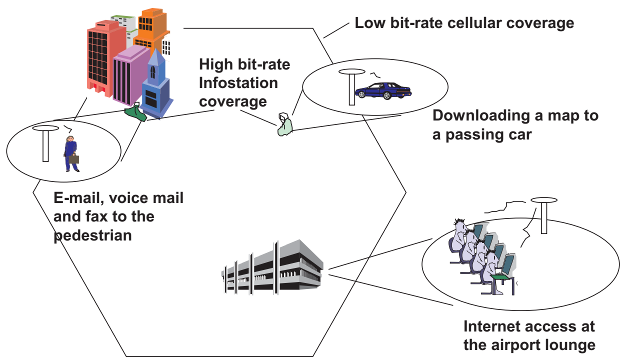

Fig. 2. Examples of Infostation services in isolated pockets of high bit-rate connectivity

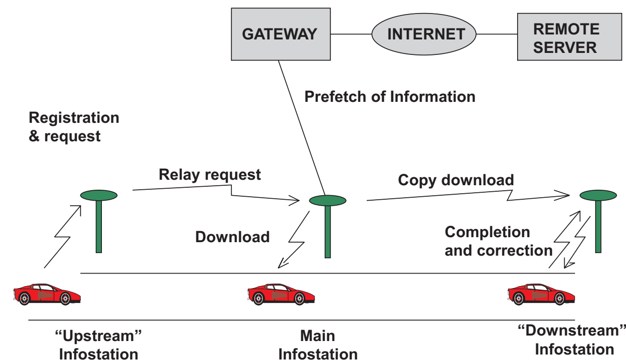

Fig. 4. Architecture for high-speed application

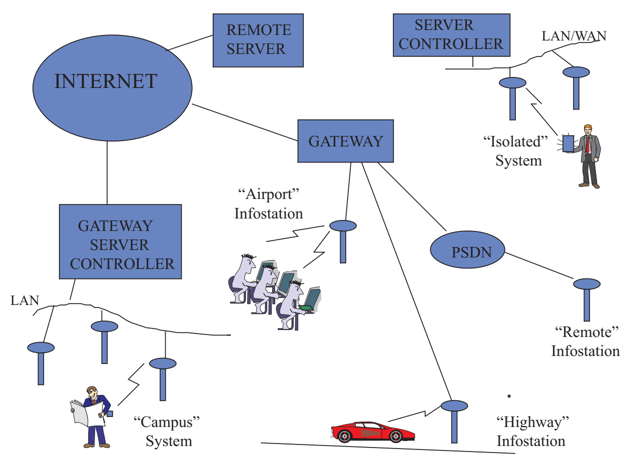

Fig. 3. Infostation system architecture

ple, might function independently homing on existing or specialized gateways to the Internet, and accessing remote servers for information and messages. The access between the *Infostation* and gateway could be wired or dial-up, depending on traffic and latency demands. In particular, the high-speed application raises issues of latency in retrieving the desired information from the network, and of having time to deliver large files. Along highways, one could enhance the system architecture with "upstream" *Infostations* at which the vehicle registers and requests information, and "downstream" *Infostations* which can complete long files and correct errors. Such auxiliary *Infostations* might possibly communicate with the main *Infostation* over the radio path, thus avoiding additional connections to the network. These possibilities are illustrated in Figure 4.

One may consider cases in which *Infostations* would be integrated into, or coordinated with a ubiquitous, low bit rate service such as cellular, or with paging or even wireline services. In addition to the configurations in which the *Infostations* are independent access ports to the Internet, geographic clusters of *Infostations* could home on local controller/servers, which would provide "campus" services in addition to Internet access. Similarly dispersed or clustered groups of *Infostations* could be organized into "isolated" systems, with controller and server functions, but without Internet access. Applications in this category include physical security (e.g. building access), financial security (e.g., ATM and credit card transactions), access to private LANS, and location dependent services (e.g., maps and advertising). We envision that the very high bit rates (and low cost per bit) which *Infostations* allow, will make practical new categories of wireless information service, and that a single set of equipment and protocols can be organized to provide very different applications in very different environments.

While radio resource management in ubiquitous cellular systems has received a lot of attention, this new system concept of isolated wireless ports requires renewed and possibly different alternatives to managing resources. Key issues that arise in designing such Infostations for supporting high-speed traffic include multiple access technologies, radio design, coverage and layout, guarantee of achievable payloads, and feasibility of radio resource management algorithms for power control and handoffs. In this paper, we identify several issues that are crucial to the successful design of these isolated high bit-rate wireless ports and focus on one particular aspect, namely the issue of coverage and capacity for *Infostations*. We analyze the impact of such constrained locations on the coverage that can be provided as well as the information that can be transferred via low cost, low power, short range base stations.

The paper is organized as follows. In Section II we list some issues in the radio design for *Infostations*. In Section III, we consider models for *Infostations* and study the analytical and theoretical limits on the capacity and coverage that can be provided by such wireless ports. Finally, we conclude by presenting some future research directions necessary for the viability of this concept.

II. Issues in Radio Design for Infostations

Due to the high data rates and the very low cost terminal that is being envisioned, our primary focus is on an *Infostation* radio channel separate from cellular or conventional PCS channels. Mobile terminals costing a few dollars are envisioned that may foster new mass markets for applications such as wireless credit cards, electronic badges and pagers. Also envisioned are high end mobile terminals for high rate services such as laptop computers, facsimile terminals, etc. The radio from the base station (*Infostation*) to the mobile terminal must be capable of transporting variable data rates upto a few megabits per second. Breakthroughs in cost, miniaturization and power consumption are required for the family of terminals. The overall economics are not changed if simplicity in the mobile terminal is sought while sacrificing complexity in the *Infostation*. Under the premise that the mobile user is not a source of large amounts of information, the communications from the terminal to the *Infostation* can be at a lower data rate. Thus a radio with asymmetric transmission rates may be a good tradeoff.

A candidate architecture being considered [5] for the above tradeoff involves time division duplex transmission with a simple amplitude modulated downlink and an uplink using a modulated reflection (also known as *backscatter* [5–7]). This technology leads to a two way radio in the mobile terminal which could cost less than a dollar. Using this technology, a stand-alone terminal with a small display could cost several dollars, and be small enough to wear as a badge. Moreover, the same device could be used as an input to a more powerful terminal such as a PDA or a laptop computer. Our radio design is motivated by three major objectives: low cost, low power consumption and a high bit-rate near the *Infostation*. The design principles make backscatter an attractive technology for our studies, although this choice is not central to the *Infostation* concept.

The coverage ranges envisioned for *Infostations* is of the order of several hundred feet with downlink data rates of upto 1 Mbps or more. The trade-offs between range of coverage and the transmission rate is studied in detail in the next scetion. To adapt to multiple situations, the *Infostations* will provide "rings" of coverage having different data rates. Data rate and framing issues also include the need to transmit large files quickly for the "drive-through" case, allow multiple access for the "sit-through" case and conserve energy for the "badge" configuration. The available bit-rate on the downlink channel will depend on the distance between the terminal and the *Infostation*, increasing with decreasing distance. As an illustration, we show, in Figure 5, the case where several bit-rates may be available for downlink transmission.

Other issues requiring investigation for the *Infostation* system concept is the protocol hierarchy for the *Infostation* architecture. This requires study of all OSI layers, from the application layer to the physical layer, and where appropriate identifying the necessary differences between various modes of access discussed above ("drive-through, walk-through and sit-through"). Issues in the physical layer include identifying minimum bit-rates for system ID and synchronization and allowing terminals to select appropriate bit-rates depending on file sizes to be transmitted. The choice of MAC protocols will depend on the type of *Infostation*. The "drive-through" *Infostation* typically deals with very few simultaneous users within the *Infostation's* range while a "sit-through" situation is closer to

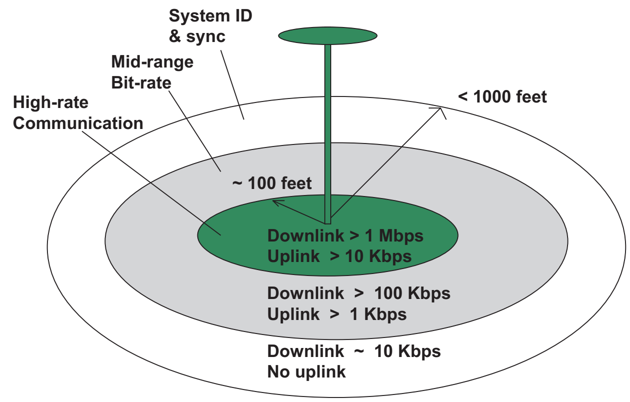

Fig. 5. Illustrative ranges and bit-rates for Infostation zones

that of a wireless LAN environment. In addition, there may also be a need to prioritize users depending on their mobility such as in an airport terminal where there may be a combined "walk-through" and "sit-through" situation. Further, since user requests may require the *Infostation* to access remote servers (and incur additional delays), there may be a need for an upstream registration and request and, a downstream completion process. These would require the coordination among groups of *Infostations* as well.

Issues in the data link layer deal with framing, flow control and connection management from the time when the user first senses the *Infostation's* presence to the time when the user leaves the coverage area. The frame design must reflect varying bit-rates that a user may require during passage through the zones of different bit-rates in an *Infostation* coverage area. Additionally, a key challenge is in dealing with the significant variations in vehicle speed and also its influence on the rate and duration of radio fading. Consequently, target protocols are required that take into account "optimal" packet sizes and error correction to account for these propagation effects. Challenges in the transport layer design include deferred connections (due to lack of adequate radio communication conditions) and limited acknowledgments (due to a narrower uplink). Issues in the application layer call for handling interactions between the client-server. In case a file cannot be received in its entirety from the current *Infostation*, the remaining portion will have to be made available at the next logical *Infostation* the mobile encounters. These require prefetching information from remote servers and local caches to reduce latency. In addition to data-on-demand, there may also be other modes of data dissemination such as publishing [8] which require clients to filter relevant information locally.

III. Coverage and Capacity for Infostations

A. *Single Infostation Model*

This model consists of an isolated *Infostation* and a mobile user which is moving in a straight line at a constant speed, v. The mobile approaches the *Infostation* and gets to a minimum distance d_{min} to the *Infostation* antenna before moving away from the *Infostation* (see Figure 6). In this model, the assumption is that because of the mobile speed or because of the distance to the next *Infostation*, it may take long before having another opportunity for communication. Hence, we want to maximize the amount of information transferred. We assume that the base station

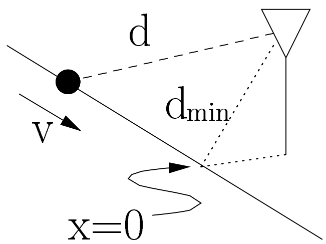

Fig. 6. Single Infostation model.

is able to operate at a transmit power P_T, the threshold value of the SNR required at the mobile receiver is γ. Without loss of generality, we assume that the mobile is moving along the x axis. We further assume an AWGN channel with noise power density N_0 and a propagation exponent equal to α. The design issue is to find the bit rate (R) for transmission and the *Infostation* coverage distance that maximize the amount of information transferred. If P_R is the power received at the mobile, the constraint in the SNR can be written as

$$\frac{P_R}{RN_0} \geq \gamma. \qquad (1)$$

Hence, the bit rate is constrained by

$$R(x) \leq \frac{P_R}{\gamma N_0} = \frac{KP_T}{\gamma N_0 (x^2 + d_{min}^2)^{\alpha/2}} = R_{\max}(x) \qquad (2)$$

where K is a constant. Let x_c be the maximum distance still with coverage. If we are using a single rate, this rate has to be $R_{\max}(x_c)$. Therefore, we have to find x_c such that we maximize the information transfer

$$I = \max_{x_c} \frac{x_c}{v} R_{\max}(x_c) \qquad (3)$$

where the ratio $\frac{x_c}{v}$ is the time spent within coverage, i.e., the duration of transaction. The optimum x_c in this case can be determined to be

$$x_c = \frac{d_{min}}{\sqrt{\alpha - 1}} \qquad (4)$$

As we can see, the distance x_c itself is not affected by the value of the mobile speed v, but it is shrunk by an increasing value of the propagation exponent α. As expected, the amount of information transferred is a decreasing function of both v and α. In order to compare the information transferred using a single rate against a continuously changing rate, we plot in Figure 7 the maximum rate possible (dependent on x) and the single rate used. In the figure, $\alpha = 2$ and the distances plotted are normalized by d_{min}. The area of the rectangle gives the amount of information that can be transferred with just one rate, whereas the area under the curve is the amount of information that can be conveyed by using a variable rate scheme. Since *Infostations* could have zones of different allowable rates, we next consider the situation of using more than one rate. This problem is equivalent to approximating the area under the curve in Figure 7 with a series of rectangles. As an

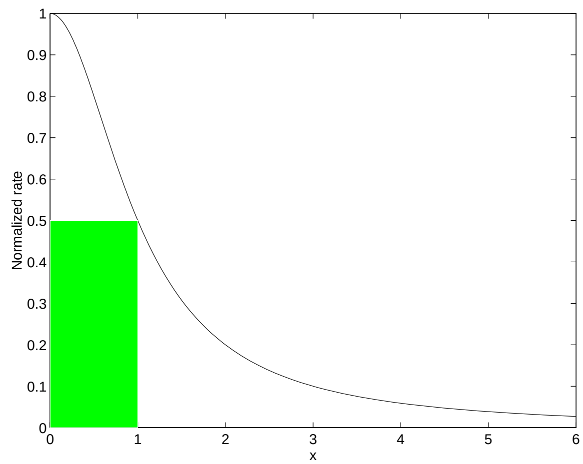

Fig. 7. Single rate

illustration, we calculate numerically the best rates when we allow the use of two, three and four different rates. The results are summarized in Figure 8, again for $\alpha = 2$, in terms of total information transfer normalized to the case of using a continuously changing rate for every position. It is seen that the improvement gained by using more rates keeps diminishing and that a large number of different rates is needed to approach the maximum information transfer achievable. The coverage distance x_c for this case is d_{min} times 1, 1.95, 3.02 and 4.24 for one, two, three and four different rates, respectively.

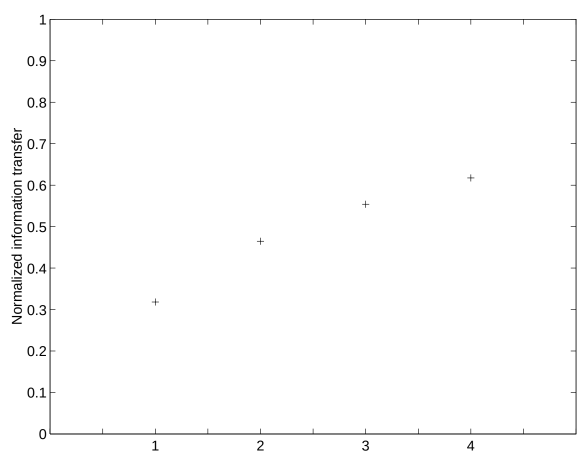

Fig. 8. Normalized information transfer for several rates

B. Multiple Infostations Model

This model extends the previous one on the assumption that we have an infinite number of *Infostations* regularly distributed, with the same distance d_{min} to the mobile's trajectory, and with distance between *Infostations* equal to $2r$. Figure 9 shows the plane that contains the mobile's trajectory and the em Infostations' antennas. As the model

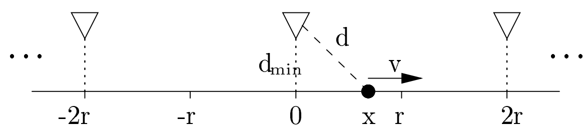

Fig. 9. Multiple Infostations model.

is periodic, we can just consider a single period, say from 0 to r, and we will assume that we have an *Infostation* at point 0. Given that the velocity of the mobile is constant, the position of the mobile at an arbitrary instant in time has a uniform pdf between 0 and r. In the following, we deal only with a propagation exponent α equal to 2.

The total amount of information transferred depends on the velocity of the mobile and the number of *Infostations* considered. To avoid this dependency, we will work in this case with bit rates. We assume that the bit rate can be changed continuously, and we find the maximum average bit rate, that is, the average capacity, defined as

$$C \triangleq \int_0^r C(x)\,\pi(x)\,dx. \tag{5}$$

where $C(x)$ is the capacity of an AWGN channel

$$C(x) = \frac{1}{2}\log_2(1 + \mathrm{SNR}(x)). \tag{6}$$

and $\pi(x)$ is the probability distribution of the mobile's position.

Two cases are considered. One case assumes that the *Infostation* has perfect and immediate knowledge of the mobile's position, and according to this information the transmitted power is varied in order to get capacity. The other case assumes a simpler transmitter that can be either on at a constant power or otherwise off. Both cases are assumed to fulfill an average power constraint.

If we can vary the transmitted power, the optimal power policy to maximize the average capacity can be shown to be

$$P(x) = \begin{cases} K(x_c^2 - x^2) & \text{for } x \le \min(x_c, r), \\ 0 & \text{otherwise,} \end{cases} \tag{7}$$

where K and x_c depend on the average power constraint. This power policy is somewhat surprising in the sense that more power is allocated when the mobile is close to the *Infostation* rather than far away. The rationale behind this fact is that the power is saved for the epochs when the channel conditions are favorable. Beyond a certain threshold distance x_c, the transmitter is simply shut off. Consequently, the idea of the limited coverage behind the *Infostations* concept is backed up. The expression for the average capacity is

$$C = \frac{x_c}{r\ln 2} - \frac{d_{min}}{r\ln 2}\arctan\left(\frac{x_c}{d_{min}}\right), \tag{8}$$

In the second case, when we cannot vary the transmitted power, the best strategy is to shut off the transmitter beyond a certain threshold distance x_c', and between 0 and x_c' use power $\frac{r}{x_c'}\bar{P}$, where $\bar{P}$ is the average power. The value x_c' can be evaluated numerically to maximize the average bit rate. Figure 10 shows an example with the two possibil-

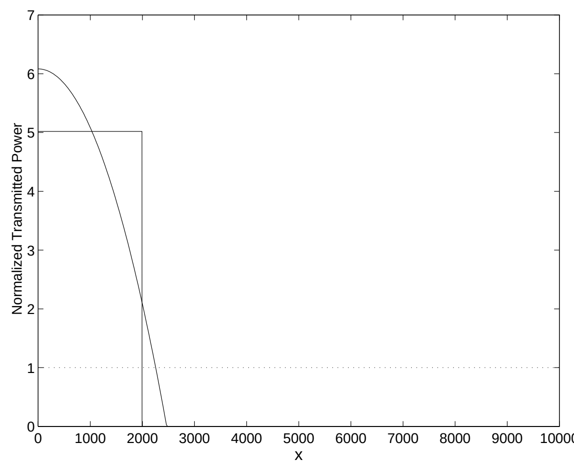

Fig. 10. Example of optimal and constant power allocations ($r = 10000$, $d_{min} = 10$)

ities for transmitted power discussed. In general, the value x_c' is less than the value x_c, i.e., the more sophisticated power control affords a larger coverage radius. Figure 11 shows the average capacity for the optimal case (variable power) and for the constant power case, as a function of r, the separation between *Infostations*. In this case, we see that the average capacity achieved by either scheme is similar. The bottom line here is that the average capacity is not so sensitive to the shape of the power control used as it is to the fact of saving the power for the epochs when the channel is good, that is, to the existence of a certain threshold distance for communication. Equivalent analysis for BPSK modulation using average cutoff rates yields similar results, with a loss of efficiency with respect to capacity but still quite insensitive to the power policy used. The threshold distances are somewhat larger. Therefore, using a simple power control seems as effective in terms of the amount of information transferred but the tradeoff is the larger coverage that a sophisticated power control scheme allows.

IV. Conclusion

In this paper we have presented a new a system alternative called *Infostations*, to existing wireless systems, that can support high bit-rate wireless data and messaging services. We have identified three different alternatives,

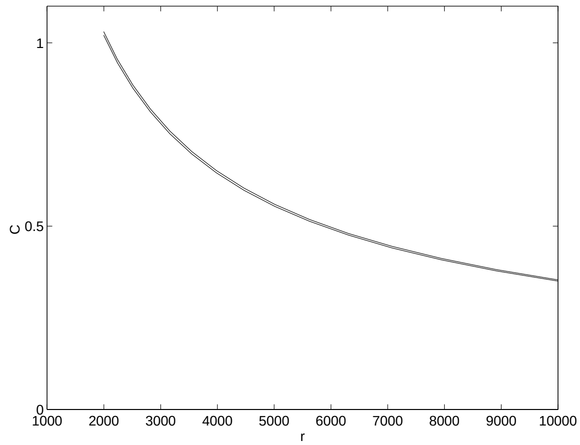

Fig. 11. Capacity as a function of r for optimum power and for constant power

"drive-through, walk-through and sit-through" to typify the range of access modes possible. We have summarized some key issues in all the protocol layers that need to be addressed for the successful implementation of such a system concept. Finally, we considered some simple yet representative models for *Infostations* to illustrate the coverage and capacity that is feasible under such a system design. Using a network of properly spaced *Infostations*, we have shown that simple power control policies can achieve almost the same capacity as a sophisticated power control scheme.

There are many commercial applications of *Infostations*. They can serve as wireless information kiosks deployed at building entrances, highways, in tunnels, at traffic lights, at gas stations, and in waiting areas at airports and train stations. Users can download voice messages, fax or email, access private LANS, retrieve web information or access location dependent information such as maps and local business directories in seconds. File sizes which would be impractical to download with conventional systems become economical, and innovative new services become possible. We see *Infostations* as revolutionary technology that can add a new dimension to mobile information services.

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