

# Wireless!

The forces and strategies that shaped a revolution



## Lecture 12

### Frequency, Wavelength and Coverage

#### Part 1- Free space path loss and the antenna effect



# Lecture 12- Classwork

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1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 12 including some important takeaways from your reading.
2. Why do higher frequency radios have less range?
3. How would higher frequency transmissions having lesser range affect the cost of a cellular system?
4. If the new systems are more expensive, why don't the new service providers charge more for service?
5. How are the new service providers disadvantaged by SG&A?
6. Do you believe that the people who asked investors for money to create systems in 1994 were aware of the risk? Do you think investors were aware of the likely results? [This is a lesson for investors, about believing that some new company in a popular and profitable business will be a "great opportunity" for investors.]
7. How might future "smart antennas" allow higher frequencies to be used in cellular systems? What might make this difficult to achieve?

# The essence of a radio system

- A radio system “modulates” a radio frequency with voice or data and transmits that electromagnetic wave into a coverage area
- The wave fills the area, spreading in every direction, growing weaker (in energy per square inch) with distance and interacting with physical objects in the area that reflect, absorb and scatter its energy
- There is also radio noise and interference everywhere



Q2

The main problem is getting a sufficient radio signal to the receiver throughout the coverage area

## Lecture 12 topics

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- The desired signal energy and the impairments are very variable
  - Signal energy is always reduced by distance, as energy expands in all directions.
  - And we will see that the amount of energy we can actually collect for our receiver depends on the size of its antenna, which depends on wavelength
    - Antennas are smaller at higher frequencies, so they collect less energy and range is reduced
    - What economic impact does it have on new systems?

The main problem is getting a sufficient radio signal to the receiver throughout the coverage area

## Lecture 13 topics (next time)

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- Energy is also absorbed, reflected and scattered by structures in the environment
  - ▣ Hills, buildings, vegetation, cars, (even raindrops)
  - ▣ These effects are wavelength dependent, so desirable frequencies depend on the particular environment
  - ▣ We will use analogies to sound and light to understand some effects at higher and lower frequencies intuitively
- We also experience large variations from “Rayleigh fading” (sharp nulls just inches apart, caused by the addition of signals that get to the receiver via different paths).

# The antenna becomes very important

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- When the radio signal (an electromagnetic wave) hits a metallic object, it causes currents to flow and some energy is absorbed by the object
  - ▣ An antenna is a metallic object whose size is specifically designed to absorb the most possible energy at a particular range of frequencies (like the 900 MHz cellular band) and to deliver a useful electrical signal to a receiver



- The receiver then uses filters and “mixers” to isolate the desired channel at a much lower frequency, where its “demodulator” recovers the voice or data.

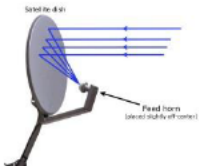
# The antenna becomes very important (continued)

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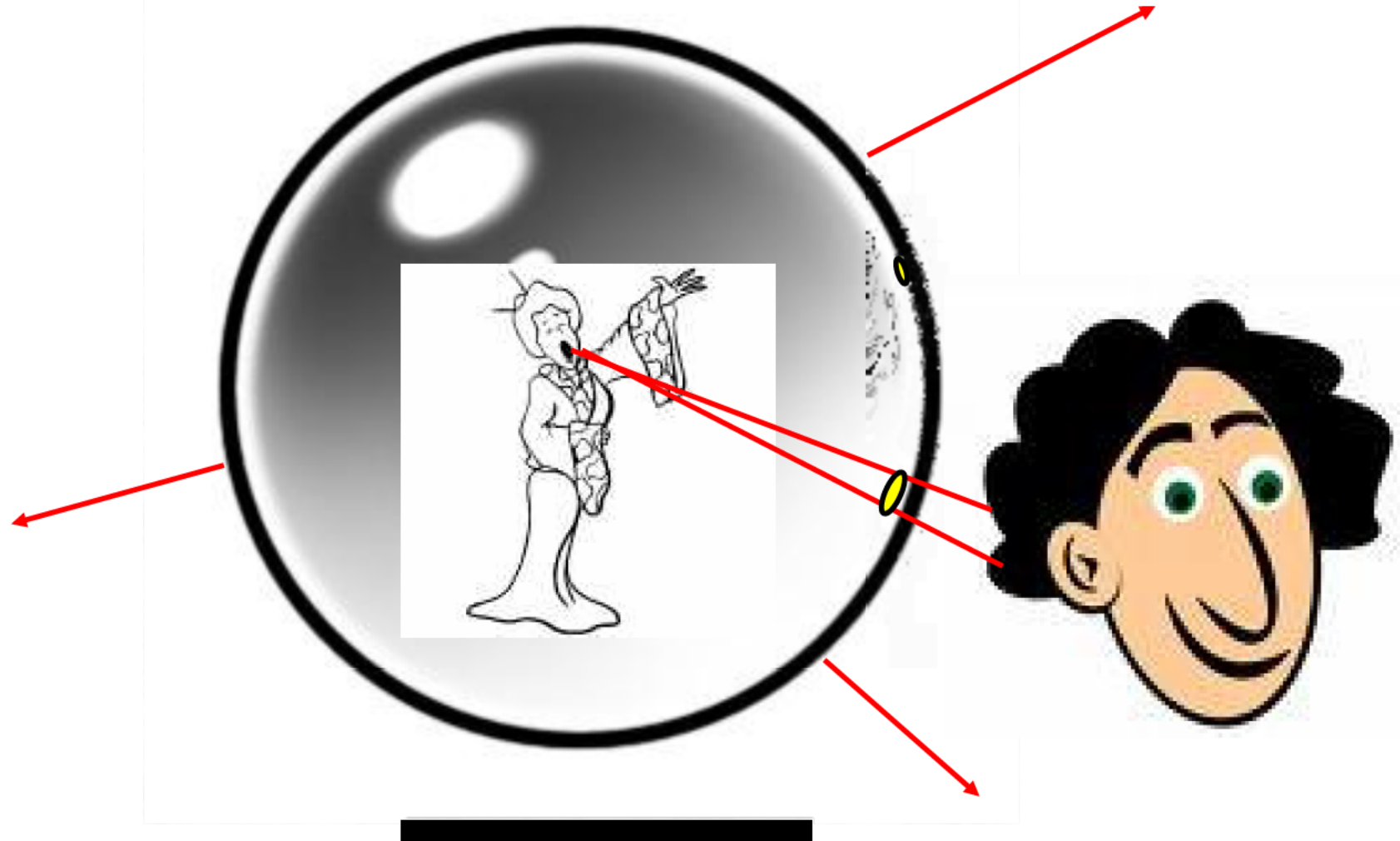
- An “efficient antenna” has a size that is related to the wavelength of the signal.



- A simple “whip” antenna (a wire a quarter of a wavelength long) is often used).
- Smaller antennas must be used for higher frequencies (shorter wavelengths), and therefore they absorb less energy and range is reduced.
- We can design larger antennas with multiple elements to absorb more energy at those higher frequencies, but those antennas become “directive” (they work better in some directions than others)



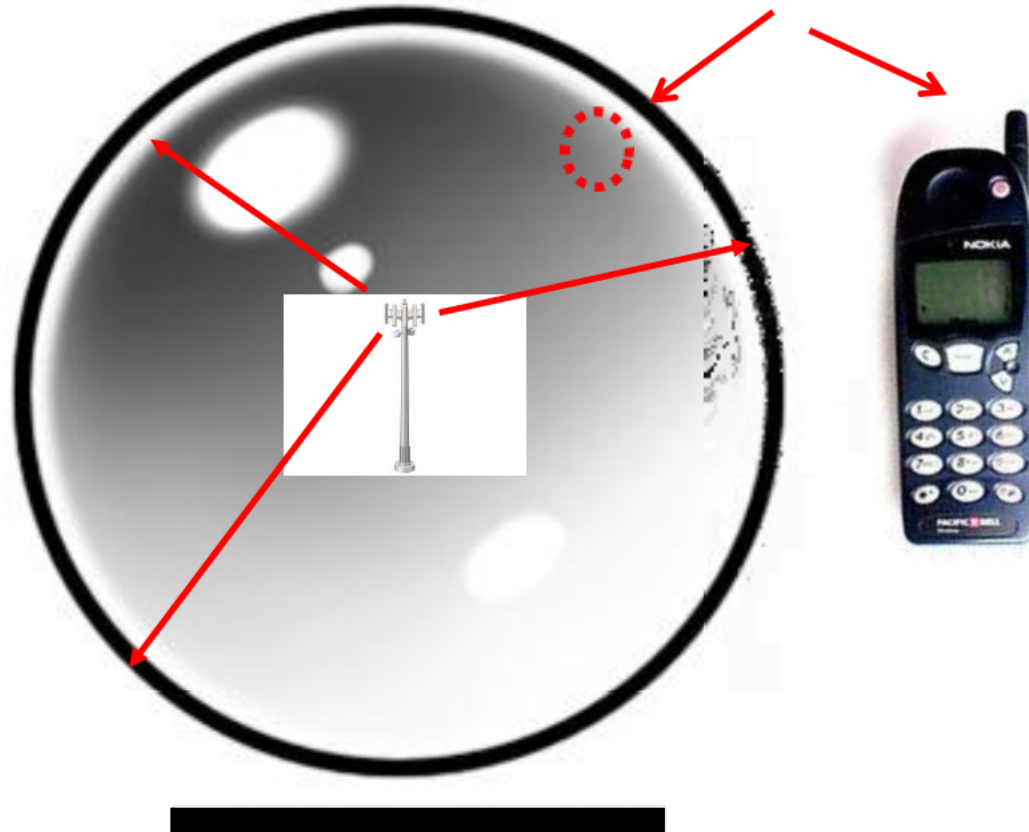
Sound energy is spread over an expanding sphere  
Our ear will capture the energy on less than 1 in<sup>2</sup> of the sphere



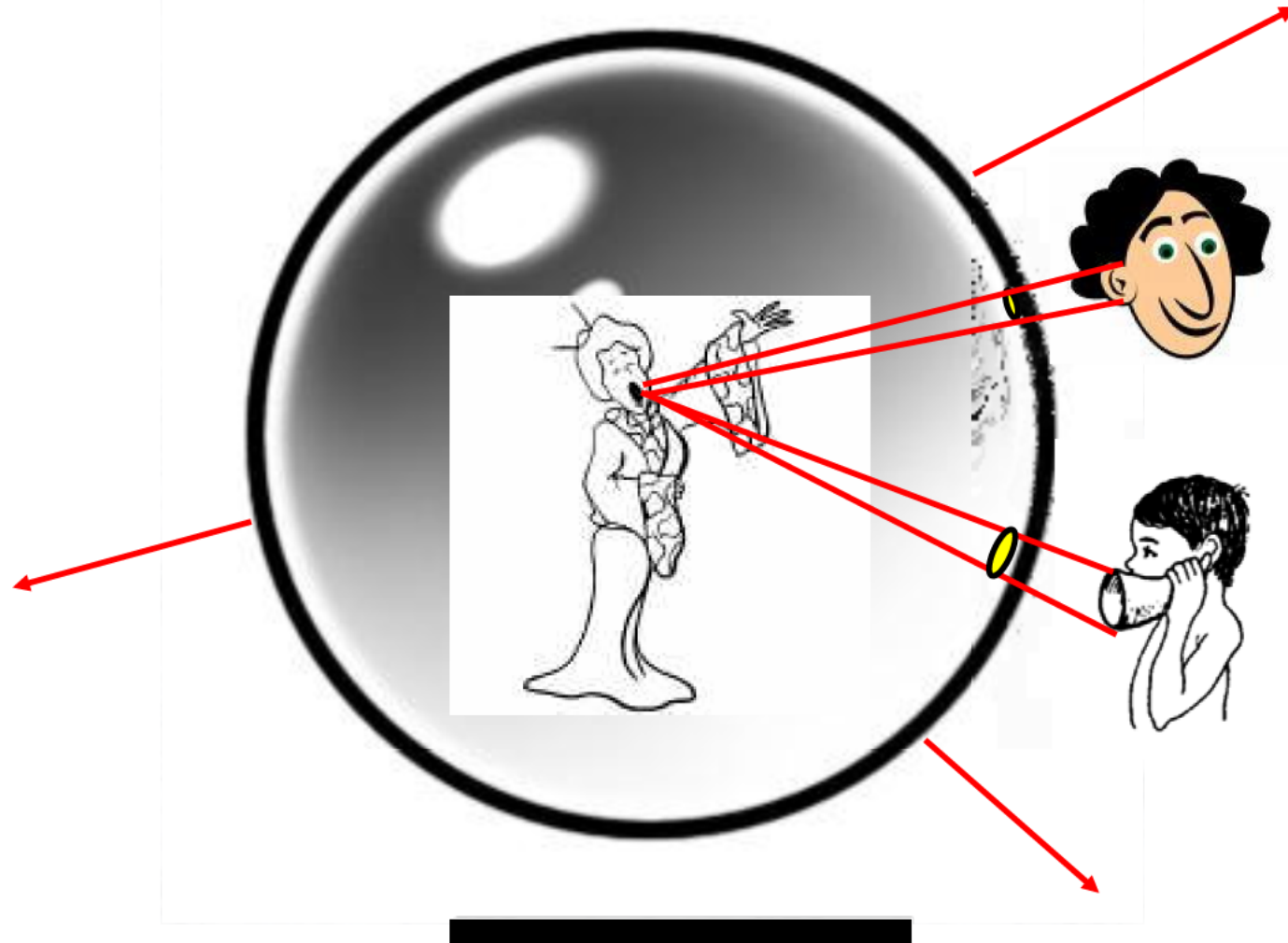
At 2 miles, the sphere has a surface area of .2 trillion square inches. 1 Watt becomes an energy density of  $5 \times 10^{-12}$  Watts/in<sup>2</sup>

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If the antenna has an "aperture" of 18 in<sup>2</sup>, it gathers a signal power of  $10^{-10}$  watts, or -100 dBw



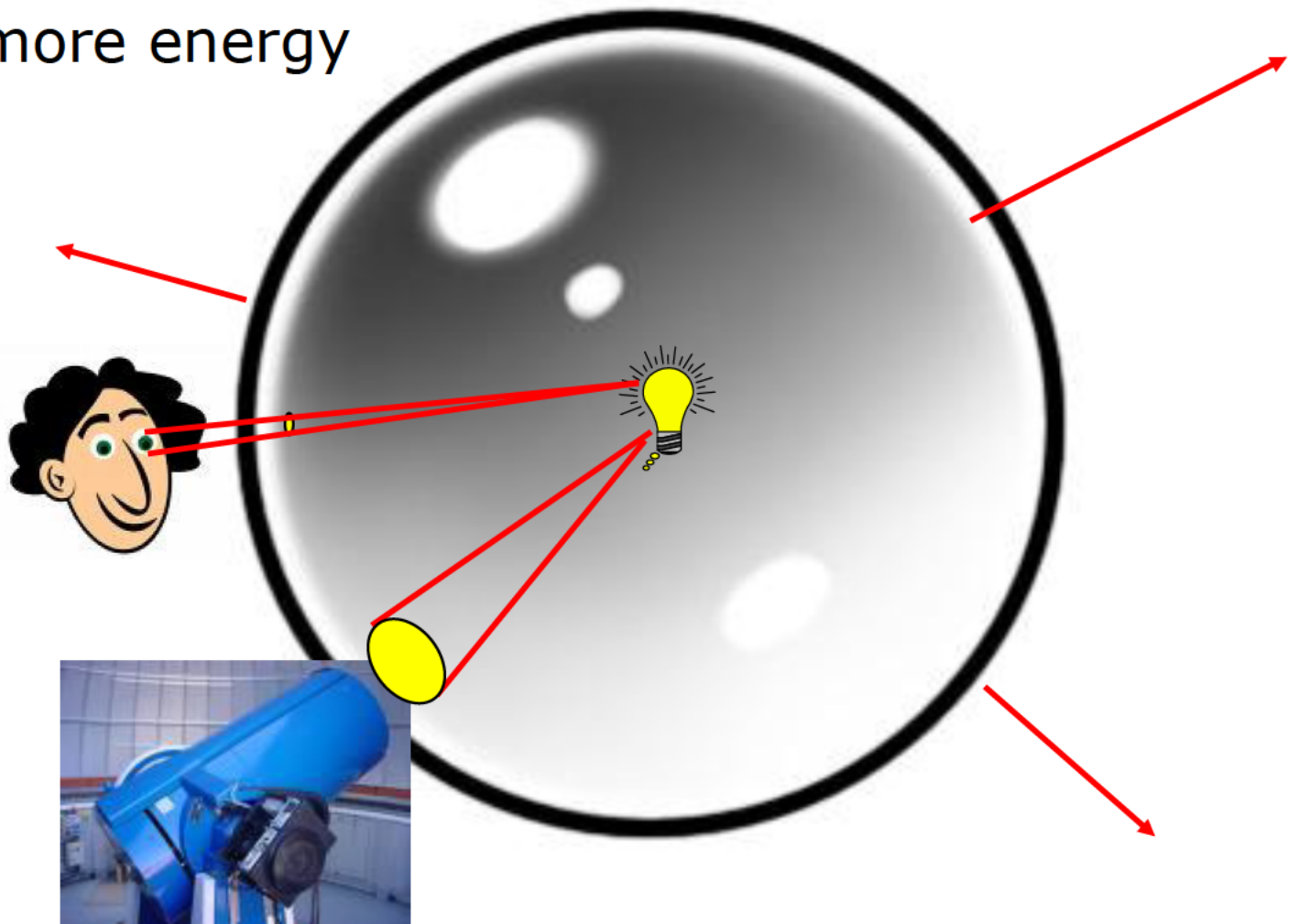
# But bigger “antennas” capture more energy



# The same is true for light energy

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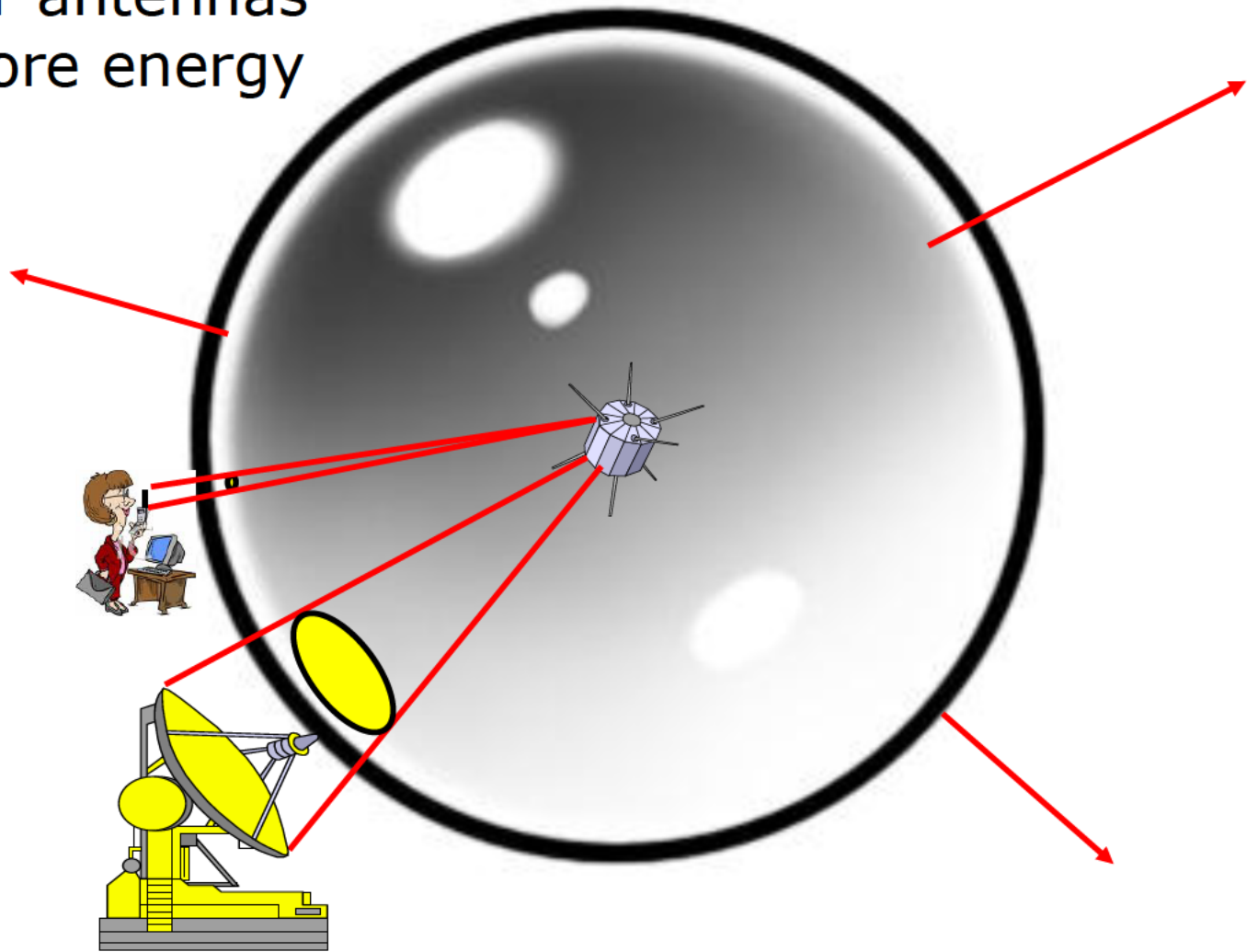
And bigger antennas still  
pick up more energy



# And for radio energy as well

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And bigger antennas  
Pick up more energy

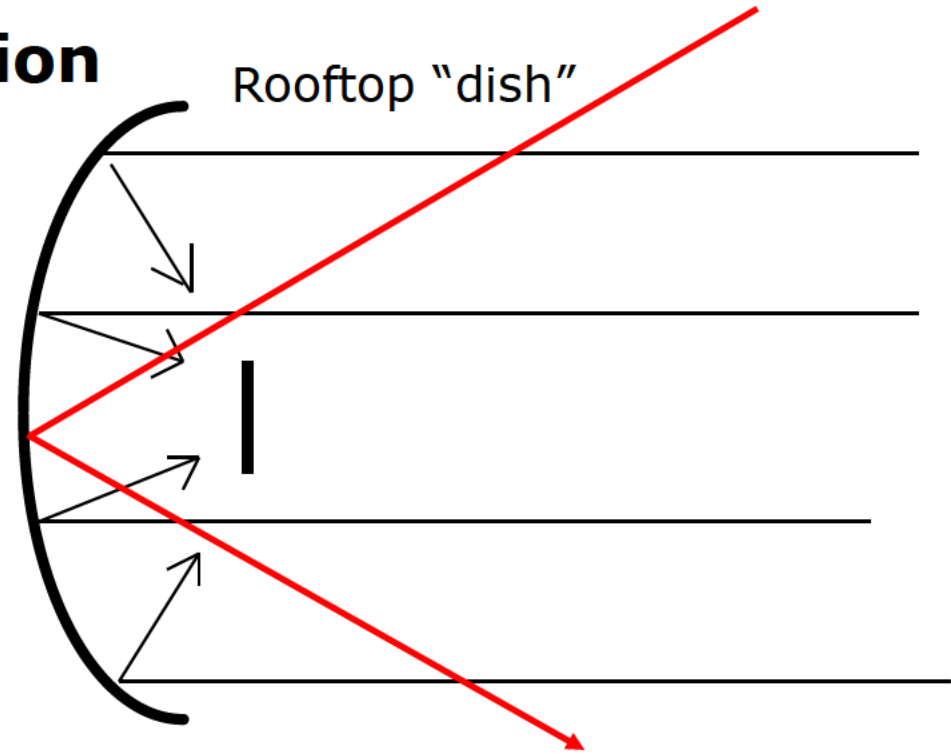
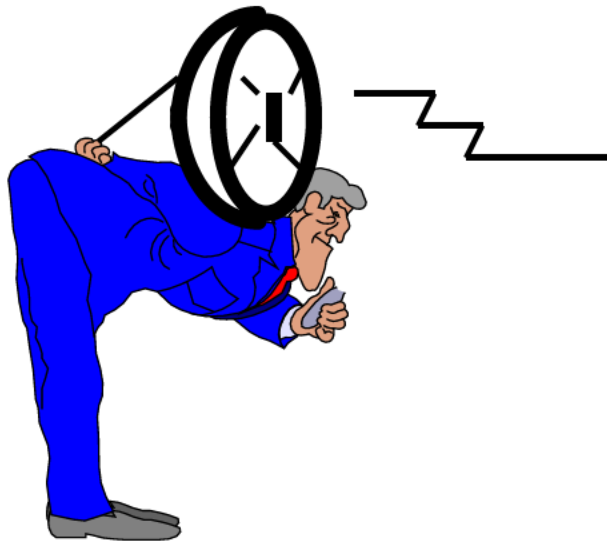


# Larger Antennas are “Directional”

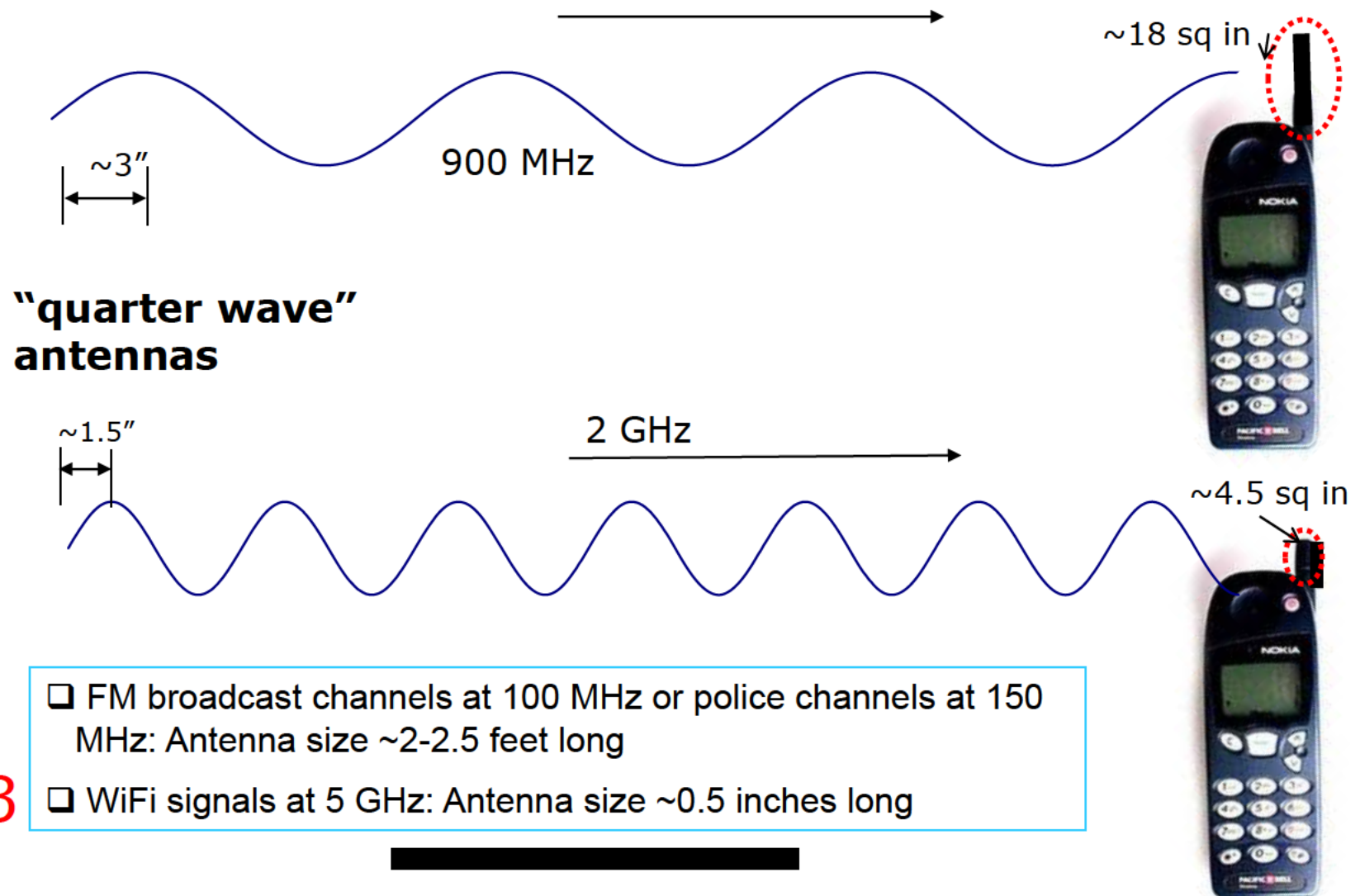
They can only gather energy from a preferred direction

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**Not an attractive solution  
for the cell phone!**



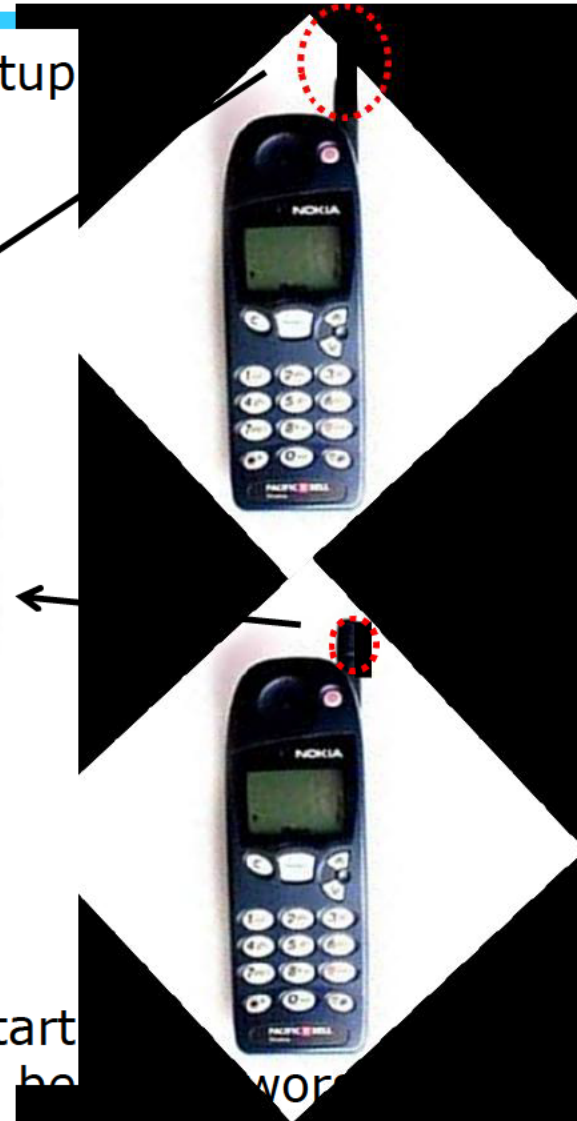
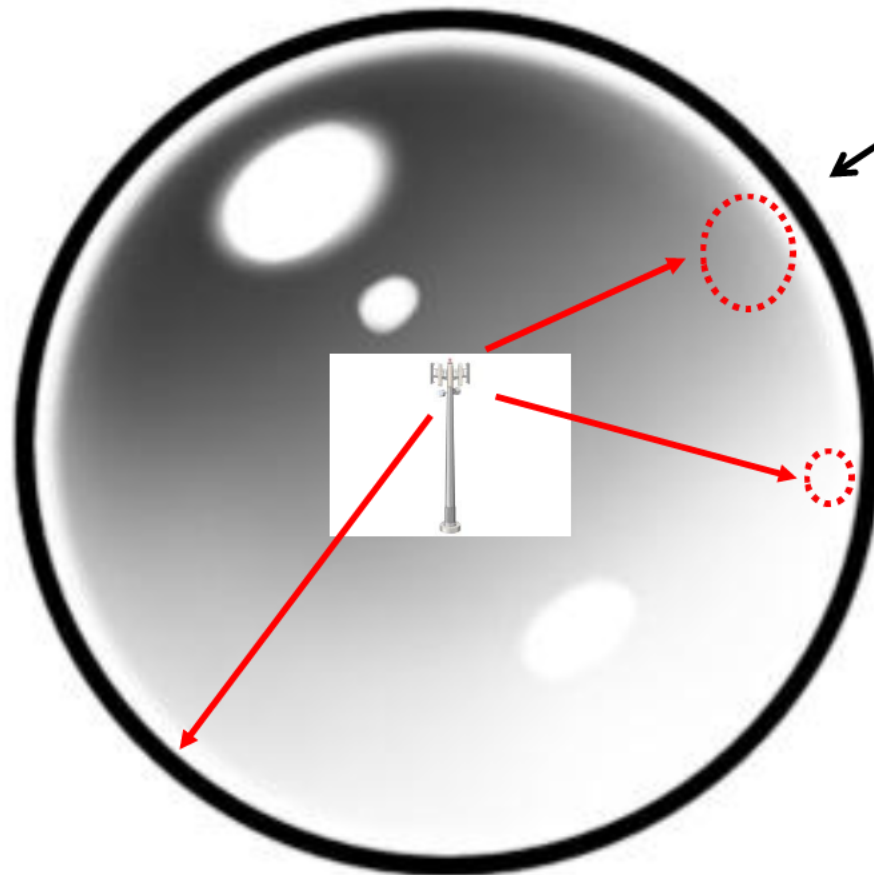
Simple antennas are typically  $\frac{1}{4}$  wave long. Their “effective aperture” is elliptical as shown below).



Q3

The 900 Mz antenna has 4x the effective aperture of the 2 GHz antenna. It will therefore capture 4x the energy on the surface of the sphere, thus allowing greater range.

This allows bigger cells (lower cost) at startup



2 GHz systems will need twice as many cells at start so twice the investment at start-up; 5 GHz would be worse

Profitability was a problem for the new cellular systems. They needed more base stations; they had to pay for their spectrum; their SG&A/user was very high; and they could only charge \$45/month

### Balance Sheet YEAR 1

|                                      |               |
|--------------------------------------|---------------|
| Number of cells=                     | 80            |
| (startup with 3-mile cells)          |               |
| Inv @ \$1M/cell                      | \$80M         |
| 25 MHz of spectrum                   |               |
| @ \$1 /MHz/POP=                      | \$250M        |
| <b>Assets (cells &amp; spectrum)</b> | <b>\$330M</b> |
| <b>Shareholders equity</b>           | <b>\$330M</b> |

Q4,Q5

### P&L for year 1

**60K users at the end of year 1**  
**= an average of 30K users**  
**Rev/user /month = \$45**  
**30K users @ \$45/mo = \$16M**

|                            |                 |
|----------------------------|-----------------|
| <b>Tot Expenses</b>        | <b>\$110.5M</b> |
| Est SG&A for 100,000 users | \$ 90M          |
| 10% Depreciation           | \$ 8M           |
| 5% Amortization            | \$ 12.5M        |

**BT Earnings** **-\$94.5M**



**The result was a disaster.**  
**They would have had to borrow about \$74M just to pay salaries**

# 5 years later things are actually worse

## Balance Sheet YEAR 5 (300K users)

|                                      |                |
|--------------------------------------|----------------|
| Number of cells=                     | 300            |
| Inv @ \$1M/ cell =                   | \$300M         |
| 25 MHz of spectrum =                 | 250M           |
| <b>Assets (cells &amp; spectrum)</b> | <b>\$ 550M</b> |
| <b>Shareholders equity</b>           | <b>\$ 550M</b> |
| Accumulated debt ?                   | \$ 300M        |

## P&L

**300K users at end of year 5 (an average of 270K during year 5)**

**Rev/user = \$43/month**

**270K users @ \$43/mo = \$139M**

|                     |                |
|---------------------|----------------|
| <b>Tot Expenses</b> | <b>\$262M</b>  |
| SG&A (\$500/user)   | ~190M          |
| 10% Depreciation    | 30M            |
| 5% Amortization     | 12M            |
| Interest on debt    | 30M            |
| <b>BT Earnings</b>  | <b>-\$123M</b> |

**They are still losing money on "operations" and are now paying interest on the money they have borrowed to pay for things like salaries, so their losses are actually increasing!**

# An example that illustrates the results for Western Wireless 1994-1999

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|         |        |      |       |       |       |       | VoiceStream<br>"spinoff" | T-Mobile buys<br>VoiceStream |      |
|---------|--------|------|-------|-------|-------|-------|--------------------------|------------------------------|------|
| Year    | 1994   | 1995 | 1996  | 1997  | 1998  | 1999  | 2000                     | 2001                         | 2002 |
| Users   | 112K   | 209K | 324K  | 520K  | 660K  | 835K  |                          |                              |      |
| Revenue | \$63M  | 146M | 225M  | 302M  | 416M  | 537M  |                          |                              |      |
| LOSS    | -\$26M | -56M | -130M | -266M | -224M | -149M |                          |                              |      |

Western Wireless was essentially created in 1994 to go into the cellular business. Its 6-year results confirm the massive losses we have predicted. Its cellular business became VoiceStream in 2000 and had two years of much higher losses before being bought by Deutsche Telekom and renamed T-Mobile. Sprint was an even bigger disaster. After merging with Nextel it had to take a \$30B loss. T-Mobile has now merged with Sprint. Are they now ready to compete (after 25 years?)

# The results including VoiceStream and T-Mobile

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|         | VoiceStream |      |       |       |       |       | T-Mobile     |      |      |
|---------|-------------|------|-------|-------|-------|-------|--------------|------|------|
| Year    | 1994        | 1995 | 1996  | 1997  | 1998  | 1999  | 2000         | 2001 | 2002 |
| Users   | 112K        | 209K | 324K  | 520K  | 660K  | 835K  | <b>25.9M</b> |      |      |
| Revenue | \$63M       | 146M | 225M  | 302M  | 416M  | 537M  | <b>1.9B</b>  |      |      |
| LOSS    | \$26M       | -56M | -130M | -266M | -224M | -149M | <b>2.1B</b>  |      |      |

**What should Deutsche Telekom pay for VoiceStream?**

Q6

# **DEUTSCHE TELEKOM OFFERS TO BUY VOICESTREAM IN \$51 BILLION DEAL**

**July 25, 2000**

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Europe's biggest telecommunication company, Deutsche Telekom AG, stepped into the U.S. market Monday with a \$51 billion deal to acquire VoiceStream Wireless Corp., the nation's eighth-largest wireless carrier.

So how did that happen? (notice the date)

# 11 months later

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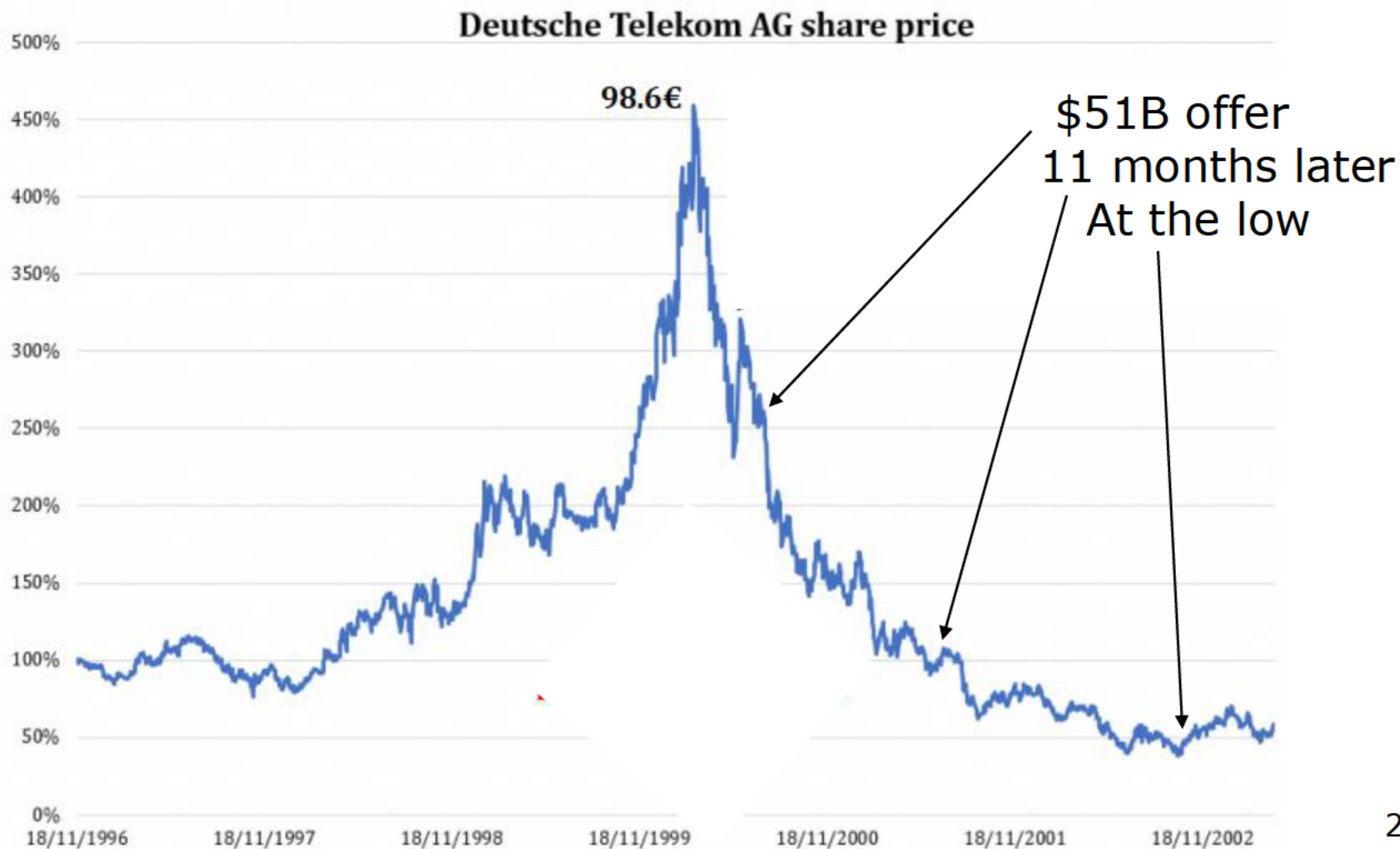
## Deutsche Telekom Buys VoiceStream

By Peter S. Goodman June 1, 2001

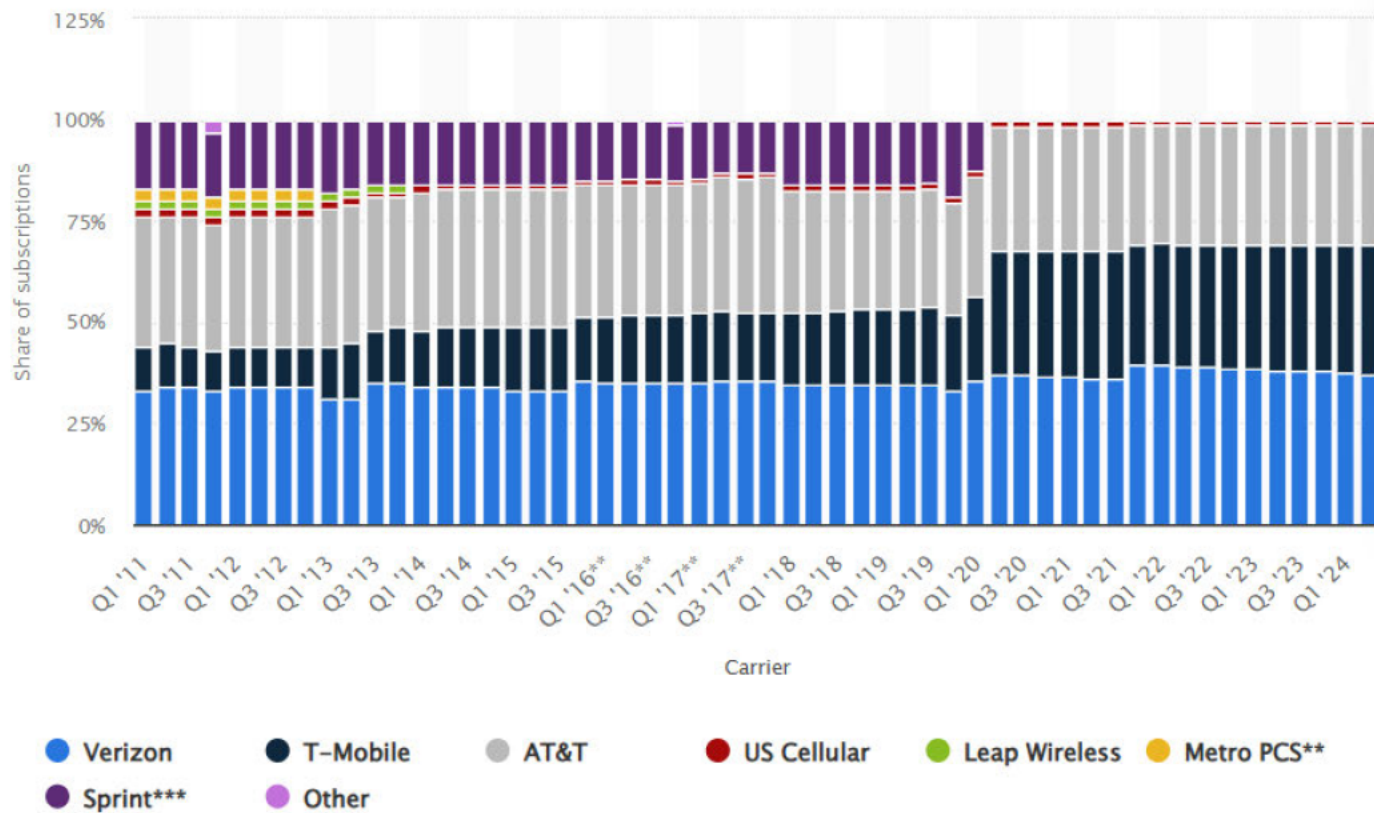
Deutsche Telekom AG yesterday closed its **\$29.6** billion cash-and-stock purchase of VoiceStream Wireless Corp., the U.S. mobile telephone company, forging a global colossus with more than 50 million customers on both sides of the Atlantic.

**What happened,  
and was that really the “final” price?**

# Watching the price fall (even after the deal)



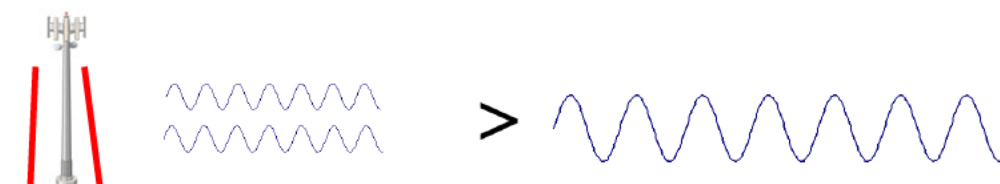
# Where are we today?



T-Mobile and Sprint Merger in 2020

# Why are the more complex antennas directional?

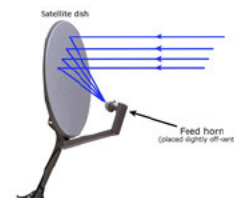
- ❑ The antenna becomes directional because it adds signals together that may have travelled different distances



Same distance to antennas-  
"in phase" signals add



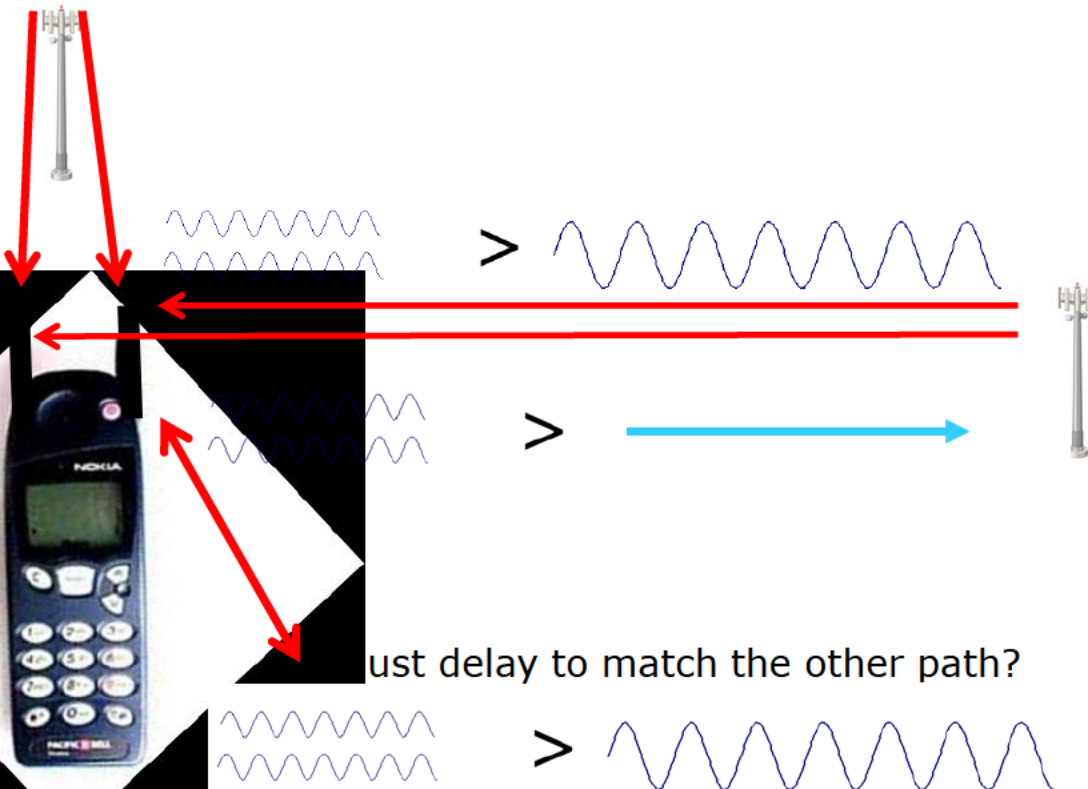
Different distances to antennas-  
signals can be "out of phase" and cancel



A "Dish" antenna has even greater problems (it only collects energy from a single direction)

Could a “smart” antenna constantly adjust the received signals from different antennas to always maximize the result?

- ❑ New cellular technology to use higher frequencies for cellular systems



Q7

Could a “smart” antenna constantly adjust the received signals from different antennas to always maximize the result?

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- ❑ Perhaps, but as strategists we have a lot of questions before we invest (many “breakthroughs” become bankruptcies)
  - ❑ Is it fast enough (like when I move my head?)
  - ❑ When will it really work?
  - ❑ How much will it cost?
  - ❑ How much processing power will it need (battery drain)?
  - ❑ How many “independent” elements can we fit on the handset?