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CONSERVATION OF RESOURCES, TELECOMMUNICATIONS, AND MICROPROCESSORS

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ABSTRACT

The energy involved in the substitution of telecommunications for travel is investigated. For the foreseeable future, the energy cost is very dependent on the bandwidth of the telecommunication mode used and may be non-trivial for certain widely-awaited broadband services. The features of narrow-band telecommunications systems are discussed and it is shown that they can be minimally-sufficient for some applications. It is further shown how the natural incorporation of microprocessors as substitutes for random logic leads to a complete elimination of any distinction between terminals for communications and terminals for dispersed data processing. This may have implications for certain policy questions now before the Federal Communications Commission.

The replacement of travel by telecommunications is an idea with obvious attractiveness in the present day [1], it holds out the promise of economizing on energy, money, personal time and, in addition, of enhancing the frequency and value of professional interactions. We shall particularly focus on the needs of scientific and technical interactions so that we are able to do what is *required* (so that the replacement for travel may be made) but no more than is *necessary* (so that the replacement is made with ECONOMY).

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We shall stress in our remarks the following points:

1. There are enormous advantages in using NARROW-BAND TELECOMMUNICATIONS channels (one or two voice-grade (VG) telephone lines, or equivalent).
2. The addition of a visual component, via a technique called Slow-Scan Televideo and of a sort which can be implemented over a narrow-band channel, provides a telecommunications capability which is adequate for many scientific, technical and managerial interactions. Accordingly, this technique gives promise of obviating travel and enhancing professional interactions.
3. The implementation of SSTV using microprocessor logic provides ultimate cost-savings and, more important, great flexibility of function which dramatically increases the utility and scope of the telecommunications medium and enhances its potential for replacing travel and fostering increased productivity.

Comparison of Energy Costs of Travel And Telecommunications

The energy considerations in using telecommunications are very sensitive to the nature of the channel used, that is, whether broadband or narrowband. Since the long-distance transmission energy costs dominate any situation except the most local, we shall ignore the energy costs of running terminal equipment and focus our attention on the energy costs per mile of separation. This enables us to compare not only different telecommunications media but provides a norm for comparison with travel as well [2].

Microwave radio links, such as the Bell System's TD-2 system, are suitable for long distance transmission. We shall see that this kind of system is extravagant in its use of power largely because we have the repeated situation of transmission units with large solid-angle radiation patterns followed by receivers collecting energy from very small portion of this solid angle. Cable transmission is more economical of power but financial considerations dictate the dominance of microwave transmission over the foreseeable future (the rise, and competitive challenge to Bell, of such microwave companies as MCI Corporation attests to this judgment).

Radio relay stations typically occur at twenty-five-mile intervals and each station consumes about twenty kW of power. Transmission paths are not geodesics but, rather, zig-zag across country. The actual transmission distance between New York and Los Angeles is about 4000 miles as compared to about 2500 air miles. In figuring distances between two points, between which people may travel or telecommunicate by different means, this factor of 1.6 X air-miles must be remembered.

We introduce the unit of a VOICE-GRADE TELEPHONE CHANNEL (VG). The TD-2 System can accommodate about 720 VG channels in bandwidth, considerations of time-sharing channels (a la TASI, for example) aside.

The energy cost PER HOUR OF USE OF ONE VG PER AIR-MILE is $\frac{20 \text{ kW} \times 1.6}{25 \text{ miles} \times 720 \text{ VG}} \times (1/.30) = 0.006$ kWh per hour per air-mile per VG assuming the efficiency for generation of electrical power is 30 per cent. We must note that this is the energy cost for telecommunications using a single voice-grade channel (1 VG). Wideband systems which have been proposed for teleconferencing use considerably more. For example, a full TV capability requires about 1000 VG of bandwidth. The energy cost is

6 kWh per hour per air-mile for FULL TV

The Bell System's PICTUREPHONE is low-resolution TV and presently requires a bandwidth of 300 VG over analog loops and 100 VG over digital transmission links. Using various redundancy elimination techniques, it may ultimately be possible to compress Picturephone transmission to 10 VG [3]. This results in the following energy costs:

0.6 kWh per hour per air-mile for PICTUREPHONE (PRESENT)
0.06 kWh per hour per air-mile for PICTUREPHONE (FUTURE)

The system we are interested in, present SSTV, currently uses TWO VG and can eventually be expected to use ONE (and possible time-shared via TASI, at that) [4]:

0.012 kWh per hour per air-mile for SSTV (PRESENT)
0.006 kWh per hour per air-mile for SSTV (FUTURE), possibly less.

COMPARISON WITH TRAVEL

A Boeing 747 with a load factor of 0.50, a seating capacity of 300, and an average speed of 500 miles per hour, consumes 3700 gallons of kerosene per hour. A round trip per passenger per mile of distance between points requires, in gallons of kerosene,

$$2 \times \frac{3700}{500 \times 0.50 \times 300} = 0.1 \text{ gallon per passenger per mile}$$

The energy content of kerosene is 39.5 kWh/gallon. Therefore, air travel by 747 produces an energy cost per round trip per passenger per air-mile of 3.9 kWh. This is actually less than the cost per hour of a FULL TV conference! The situation is somewhat worse for a 727 with sixty-five passengers and a load factor of 0.67, an average speed of 500 miles per hour and a kerosene consumption rate of 1200 gallons per hour. The round-trip energy cost per passenger per air-mile of separation works out to be 4.35 kWh.

In sum, a round-trip per passenger from LA to NY, or a teleconference between two people, one in LA and the other in NY, would cost (in energy) as follows:

747 Air Travel:	9740 kWh
Full TV:	15000 kWh per hour of use
Picturephone:	1500 kWh per hour of use (PRESENT)
Picturephone:	150 kWh per hour of use (FUTURE)
SSTV:	30 kWh per hour of use (PRESENT)
SSTV:	15 kWh per hour of use (FUTURE), OR LESS!

The Sufficiency and Minimality of Slow-Scan Televideo

We have initially mentioned the necessary attributes of SSTV: we may term them sufficiency (the ability to do what is required in order to replace some travel) and minimality (the injunction to do no more than is necessary so that the replacement may be made with economy). It remains to argue the sufficiency of slow-scan televideo.

We state at the outset that the goal is not to replace *all* travel. A more restricted aim will be seen to have a better chance of success than the more hyperbolic claims of the enthusiasts of the "wired-city" concept. We must first of all make some observations about travel in organizations such as corporations, laboratories, etc. It is probably a general pattern that the number of trips per person per month increases as one goes up through an organizational hierarchy. For example, a study at Los Alamos Scientific Laboratory indicated that staff members averaged between 0.1 and 0.2 trips per month; supervisors, 0.5; Group Leaders, 0.8; Division Leaders, 1.8; Assistant Directors, 2.6; and the Director, 2.8. This is not to say that one is most effective in replacing travel by addressing the needs of the most-traveled elements in the hierarchy: there are many more indians than chiefs. The nature of the interactions for which travel is undertaken is, likewise, different as one goes up through the structure. The major part of the travel (because of their greater numbers) is done by the scientists and engineers and middle managers who are concerned with the actual work on projects rather than the higher-level management who are often more concerned with making the decisions as to resource allocation in different areas. This distinction is important, since the communications system in question addresses the specifics of the interactions among working scientists, engineers and middle managers. *Psychology Today* advertises a *Body Talk* game (based on *Body Language*) predicated on the idea that 93 per cent of the "impact" of a personal confrontation is non-verbal [5]. It may be the case that personal contact is more necessary in the case of high-level managers who are frequently concerned with evaluating the person making a presentation as much as with the details of the presentation. To serve this function, a broadband telecommunications system might be desired to simulate the personal interview situation as closely as possible. One might want motion and perhaps even full color to "see the countenance pale, the hands tremble, and the beads of sweat form."

We submit that the contact primarily needed among scientists and engineers is of a different nature, being predominantly *informational* rather than *affective*. The telephone alone would suffice for many such interactions were it not for the fact that, while primarily *aural*, such interactions do have a significant *visual* component for graphics, mathematics, pictures, etc. It has been estimated that normal personal interactions (in the same place) are 95 per cent aural (ignoring "impact," whatever that may mean) while scientific and technical discussions raise the visual component from 5 per cent to about 15 per cent. The need for blackboards and chalk is much more apparent in the circles of scientists and engineers (and the managers who come from their ranks) than elsewhere.

Slow-scan tele*video* involves the transmission of still pictures only and not more often than once every thirty or so seconds [6]. A simple argument shows that this restriction permits the use of a single ordinary voice-grade telephone channel. A TV channel is approximately 4.5 MHz in bandwidth. A telephone VG channel is about 1000X less than this in bandwidth. Full TV resolution in tele*vision* involves the transmission of thirty frames per second in order to convey the appearance of motion. If we do not send thirty frames per second, however, but rather only one every 33 seconds, we see that the information rate (and hence the needed bandwidth) is reduced by $30 \times 33 = 1000$. Full TV resolution, therefore, may be transmitted by tele*video* over an ordinary telephone line a few kilohertz in bandwidth.

To see that motion is not needed in many applications, we may take as our model for conducting a conference either a blackboard or, less retrograde in our modern era, an overhead projector. This has largely superseded the blackboard at scientific conferences and presentations and provides a good simulation of a personal scientific interaction: we show our fellow conferees pictures, pre-prepared graphics and calculations and we write and draw new graphics and mathematics in real time, all the while engaging in two-way voice interaction. The important point to be emphasized is that *motion is not generally required.* Further, the visual presentation does not change very often, certainly not more often than every half-minute. This argument implies that we have obtained the availability and flexibility of a narrow-band link such as a telephone line at the expense of the right parameter. Our experience at Northwestern University in both education and general teleconferencing has so far borne out this judgment [7].

At least three possible areas of use should be considered promising for SSTV: "casual" personal interaction, usually on a one-to-one basis, extending the value of an ordinary telephone call; teleconferencing, in which several scientists/engineers/middle managers in different locations "meet" in a seminar or a conference-type interaction (this may be either a "democratic" conference in which all participants are equally talkers and listeners or a "1 to n" conference in which one speaker has the floor with the others able to ask questions and make comments); trip-value enhancement, in which a personal visit to another site is "backed up" by tele-consultation with colleagues and support staff back at the home installation. It should be emphasized that savings on travel may be the least of the benefits; not only will some travel be obviated but the *quality of professional interactions* will be enhanced. It is to be expected that better allocation of resources and greater creativity and productivity in scientific and technical fields will result.

Narrow-Band Telecommunications and Microprocessors

A natural marriage is in the offing between SSTV and micro-processors. The reasons have to do with economies of scale, additional capability, and the irresistible trend of technology.

At the moment, the major cost item in SSTV is the terminal equipment rather than the channel. There are two major cost elements here, the memory and the control logic. The LANTEL (*L*os *A*lamos-*N*orthwestern *TEL*evideo System) development has addressed the economies of scale possible in the memory area by implementing a design based on solid-state MOS shift register memory. The cost of this (and its lineal descendants: CCD, bubble, etc.) is coming down because of the constant and continuing effect of the two "learning curves" in the semiconductor industry (increased yield and increased density of components as the volume increases) [8]. The prototype LANTEL System had 105 IC's for the control logic. It is not the parts costs of these so much as the cost of assembly and checkout. Replacing all or *most* of these IC's by one or more microprocessors would greatly *reduce the assembly and checkout* needed as well as provide *increased reliability* and ability to *diagnose* both fabrication errors and malfunctions subsequently. There are some fast control functions which would require faster microprocessors than are immediately available (although Motorola's announced 10800 series might be fast enough to do the whole job) but it may in fact be just as well to do the fast logic in hard-wired fashion and use the microprocessor for the rest. This would relieve the CPU and provide more time for various "smart" functions.

Among the additional capabilities which the implementation of a microprocessor would facilitate are the following: Voice-over-video (the use of a single shared telephone channel for both voice and video information with the possibility of time-sharing even beyond that should study of the statistics of such usage indicate its value); memory reconfiguration (use of the same memory elements to trade off between resolution, gray scale, color, format, multiple frames—the importance of which we have stressed elsewhere—, etc.); efficient data transmission (differencing techniques, *redundancy elimination*, use of Hadamard and other transforms, etc.); image processing and pattern recognition; manipulation of data displays; *encryption* (to provide secure teleconferencing) etc.

A glance at the characteristics which must be matched between application and microprocessor fits this situation:

APPLICATION CHARACTERISTICS WHICH INFLUENCE THE CHOICE OF MICROPROCESSOR ARCHITECTURE

1. Volume and type of I/O
2. Response time to external events
3. Need for asynchronous operation with external environ
4. Amount of internal data storage and program storage
5. Volatile or nonvolatile R/W memory requirements

IMPORTANT MICROPROCESSOR CHARACTERISTICS

1. Interrupt system	—single or multilevel vectored or nonvectored
2. I/O system	—control within processor or via external control and data bus width- and time-multiplexing
3. Instruction set	—instruction timing microprogramming capability
4. Register availability and usage	—dedicated and general purpose registers; time multiplexing
5. Memory capability	—types, sizes, speeds, memory addressing, logical and electrical interchangeability

A simple example is the problem of using a small number of bits to address a large memory. The serial nature of the memory in this application obviates many of the "effective addressing" schemes usually involved to use microprocessors.

Finally, the trend of other technology indicates that this approach is correct. We note that CPU's for full-size computers can only get so large: the speed is already limited by the physical dimensions. In the recently installed CRAY I, the maximum lead length is four feet and the speed was largely achieved by clever geometric placement of components. The velocity of light and the spatial dimensions provide an ultimate limit and it is close to saturation now. DISPERSED DATA PROCESSING (DDP) is the only answer in sight. Long leads are used only to transmit reduced data of signals to initiate implementation of algorithms stored at the more remote locations.

The STEGOSAURUS experienced this problem a long time ago. It was so long that it took too much time for a signal to travel from its head all the way back and a highly developed nerve cluster, some twenty times larger than its walnut-sized brain, evolved as a nerve relay station in its hip needed to control the massive hind quarters and the tail muscles, much as a tillerman controls the rear part of a hook-and-ladder fire engine. The "dinosaur with two brains" had certain advantages, as pointed out by Bert Leston Taylor:

> Thus he could reason *a priori*
> As well as *a posteriori*.
> No problem bothered him a bit;
> He made both head and tail of it.
>
> So wise was he, so wise and solemn
> Each thought filled just a spinal column.
> If one brain found the pressure strong
> It passed a few ideas along.

If something slipped his forward mind
Twas rescued by the one behind.
And if in error he was caught
He had a saving afterthought.

As he thought twice before he spoke
He had no judgment to revoke.
Thus could he think without congestion
Upon both sides of every questions.

The point, of course, is that DDP leads naturally and inescapably to the idea of the SMART TERMINAL. Our proposed SSTV terminal with microprocessor logic is another approach to the same asymptotic configuration, albeit starting with the idea of a telecommunications device. We submit that this is probably a good reason to believe that both approaches are likely to be correct leading as they do to the same conclusion.

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