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Channel Uncertainty in Communications

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Channel uncertainty in general communication systems, and wireless systems in particular, is an unavoidable element. This uncertainty may take different forms and have different causes. Channel measurement error may be the first to spring to mind. As channels vary in time and frequency, the necessarily finite amount of energy available to a system for measurement fundamentally limits the accuracy of channel estimation and, hence, what use we can make of such measurements. Moreover, in systems where very wide bands are used, we may in effect consider that, owing to decorrelation in frequency, we are dealing with not just one, but many channels. The applicability of capacity-achieving schemes, particularly in the asymptotic regime, is heavily affected by channel uncertainty. Channel measurement uncertainty is also often pointed to as the root cause of the difficulty of implementing, in practice, many schemes that are appealing from an information-theoretic perspective, such as interference cancellation in multiple access systems.

Channel uncertainty also plagues systems in which channel variability is non-existent or minimal. Uncertainty in the channel is an important component of wireless local area networks (LANs), yet many of these are designed for situations in which the propagation conditions are fixed or changing very slowly. Network operating conditions are then of paramount importance - the channel consists not only of the propagation, but also of the very dynamic interference from other users.

Finally, even if a channel is quasi-static and interference minimal or well known, uncertainty regarding the channel modelling remains. While great progress has been made in the modelling, both experimentally and theoretically, of many types of channels, the models used for development of theoretical advances are necessarily simple and tractable. The gap between channel model and actual channel behavior may be considerably more pronounced than the difference between channel measurement and channel realization. Yet, this gap may be particularly difficult to quantify and few results are available to gauge the robustness of our methods to the shortcomings of our channel modelling.

In this paper, we do not seek to provide a comprehensive, or even partial, overview of channel uncertainty and its effects on capacity. The topic is broad, complex and technically challenging. Excellent overview papers on this topic exist [LN98, BPS98] and it remains a vibrant area of research [LS02, GLT00]. Nor do we seek to address the difficult issues of channel modelling [Jak93]

Editor's Note: The paper "The Effect Upon Channel Capacity in Wireless Communications of Perfect and Imperfect Knowledge of the Channel," by Muriel Medard, which appeared in the May 2000 IEEE Transactions on Information Theory, was awarded the 2002 IEEE Leon Kirchmayer Award. This invited paper is the author's reflections on her prize winning paper.

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From the Editor

Lance C. Pérez

This issue of the IEEE Information Theory Society Newsletter contains two articles by recent paper award winners. The first, by Muriel Medard, explores themes addressedd in her paper "The Effect Upon Channel Capacity in Wireless Communications of Perfect and Imperfect Knowledge of Channel," which was awarded the 2002 IEEE Leon Kirchmayer Award. The second article, by Michael L. Honig and Weimin Xiao, reflects on the paper "Performance of reduced-rank linear interference suppression," which was awarded the 2002 Commmunications Society/Information Theory Society Joint Paper Award.

The Information Theory web site has been moved to http://www.ieeeits.org/. The IT web site is full of useful information including pdf versions of the Newsletter. In fact, a pdf version of the most recent Newsletter is posted on the web site soon after it goes to press. For IT members living outside the United States, this may offer more timely access.

The IT web site also contains a link to the IT Digital Newsletter archive at http://www.cparity.com/it/demo/welcome.htm. This archive contains Newsletters dating by to 1954.

Please help make the Newsletter as interesting and informative as possible by offering suggestions and contributing news. The deadlines for the 2003 issues of the Newsletter are as follows:

Issue	Deadline
September 2003	July 15, 2003
December 2003	October 15, 2003

Electronic submission, especially in ascii and Word formats, is encouraged.

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President's Column

A.J. Han Vinck, University of Duisburg-Essen, Germany

This message is written in the beginning of April. The war in Iraq and an outbreak of an atypical pneumonia known as Severe Acute Respiratory Syndrome (SARS) in Hong Kong have dominated the news since early March. The World Health Organization has issued a travel warning to Hong Kong and Guangdong, a province in South China. Our members are concerned about traveling to Hong-Kong and Japan in order to participate in the IT Workshop and ISIT2003 in Yokohama. In view of these developments, the local organizing committee of the 2003 IEEE Information Theory Workshop made the difficult decision to cancel the Hong Kong workshop. The decision was unavoidable and can only be respected. It must have been a great disappointment for Raymond Yeung, Victor Wei and all others involved. I very much sympathize with them and hope that they do not suffer any negative consequences.

The spring IT workshop took place in Paris, March 30 – April 5. It was very well organized under the leadership of Joseph Boutros and Aaron Gulliver as general chairmen. Due to the involvement of Joseph Boutros and his staff, the participants enjoyed a very interesting workshop in the old historical buildings of the Sorbonne. The technical and social quality was high and the open sessions were very much appreciated by the nearly 150 participants.

The Board of Governors meeting in Paris was well attended by about 13 Board members and 5 guests. One of the main topics during the meeting was the financial situation of our society. Due to the financial problems within IEEE, the society is forced to find additional capital to balance the budget for the year 2004. Part of the solution, approved by the Board, is to change the structure of the membership fee. Important cost factors for membership, in addition to (unexpected) IEEE charges, are the production of a paper version of our transactions and the mailing costs. We therefore created two types of membership:

a. $30 for the regular membership without a paper version of the transactions

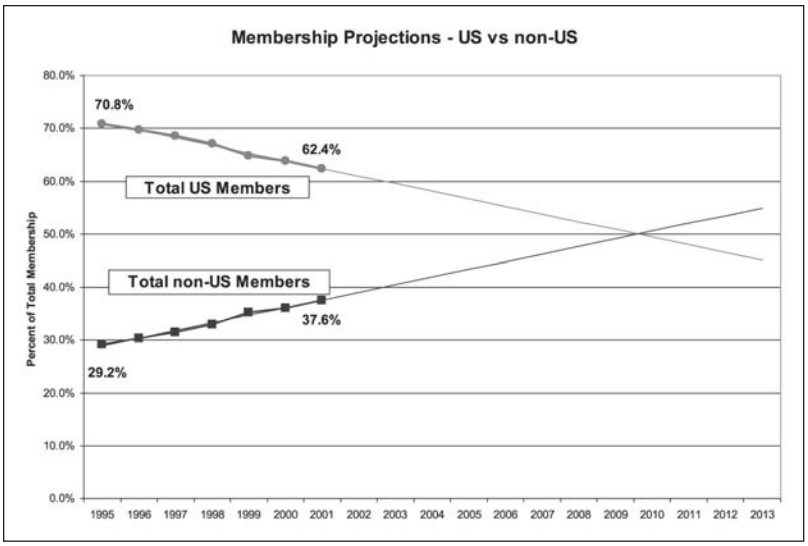
b. $60 for the regular membership including a mailed paper version of the transactions

Aaron Gulliver, Han Vinck and Joseph Boutros.

The same strategy is followed by other societies. It is called unbundling. As pointed out in the previous newsletter, it is very difficult to budget in a situation where we very much depend on what happens at the (unpredictable) IEEE level. Our treasurer Marc Fossorier is doing a great job for our society in handling all the details. Our goal is to keep the costs low. Note that they are still far below the real costs of our product.

Aaron Gulliver stepped down as secretary of the society after 3 years of diligent work. In addition to his normal work as the secretary, he also maintained the IT web-site. We greatly appreciate his contributions as a volunteer in our society. The Board approved the appointment of Mehul Motani from Singapore National University as his successor.

The Board also discussed the value of membership in the IT Society. This becomes a very important topic for the future, since many larger organizations in the USA now have access to the IEEE Electronic Library (IEL). If you work or study in such an organization, there is no need to be a member of IEEE to obtain the publications of the societies. This of course re-



duces the membership of the societies dramatically. Another factor influencing our membership is the unbundling of publications. Once someone becomes an IEEE member, they can order publications from many societies without being a member of the particular society. In the future, this will include the IT Transactions. This group is probably very large, especially outside USA. The following figure (produced by IEEE) gives the expected membership trend for the IEEE for USA and nonUSA members. In our society, about 50% of the membership comes from outside the USA. We have to improve the participation of these members in our organization.

For our members the quality of our transactions and newsletter is of utmost importance. It is the most respected journal in our field and we are very proud of that. Paul Siegel as Editor in Chief reported on the IEEE Transactions review in the previous newsletter. The conclusion is that the IT Transactions and the IT Newsletter are well managed, financially sound, and meet the quality standards set by IEEE. We are ranked 13 out of 220 electrical engineering journals. During the Board meeting the time between submission of a manuscript and reception of the final reviews was discussed. This period must be short to be attractive for publishing new results. Authors, reviewers and associate editors play a key role in this process. The author has the responsibility to present his results in a clear and concise way. Furthermore, submission of a manuscript automatically means that you are also available as a reviewer. In my (maybe European) opinion, you cannot publish if you do not review. Reviewing and editing is a time consuming process that directly influences the quality and attractiveness of our transactions. Frustration of potential authors should be avoided. Paul is requested to give his opinion on this at the next Board meeting in Yokohama.

The photo includes Prof. Jiunn-Tsair Chen (NTHU, the 4th from the left), Prof. Chi-chao Chao (NTHU, the 7thfrom the left), Prof. Hsiao-Hwa Chen (NSYSU, the 8th from the left), Han Vinck (the 9th from the left) and Prof. Chung- Yung Chi (NTHU, the 10th from the left). The others are our student members.

To further improve the value of membership, the education committee is expected to be able to play an important role. The internet can be used to link to, or offer Information Theory related materials like: tutorials; educational material; courses; book reviews for educational purposes; class notes; educational software/hardware. It is highly appreciated that at ISIT2004, Chicago, the organizers Daniel Costello and Bruce Hajek will organize tutorials. Ivan Fair (University of Alberta) has agreed to be the new chair of the education committee. His ideas will follow soon in subsequent newsletters or can be found on the web site. New initiatives and help are very much appreciated.

Chapters improve the value of our membership at a local level! In the previous newsletter I reported on the benefits of chapters and additional information may be found on our web site. They can be considered as local representatives of the society. In March I visited National Sun Yat-Sen University (NSYSU) in Kaohsiung and the National Tsing Hua University (NTHU) in Hsinchu, Taiwan. In addition to a series of technical talks the local Information Theory Chapter invited me as a distinguished speaker of the IEEE Information Theory Society. Present and former members of the Board are distinguished speakers of the society and can be invited by any IEEE entity. For the conditions, please have a look at our web site. After the lecture I used the opportunity to discuss with the students and local members of the chapter about their activities in Taiwan. The Taiwan chapter is very active. It has about 250 members and two major events per year.

In the next newsletter I hope to be able to report on further developments in our society and a successful ISIT in Yokohama.

The Historian's Column

A. Ephremides

Recently, I was looking at the dangerously high pile of past Transactions in my office (I still haven't become accustomed to scanning the digital library) and picked from the very bottom my very first issue. It was the March 1968 issue. I was a first-year graduate student then and this was my first tangible and prized possession after I joined IEEE in the beginning of my second semester at Princeton. Looking at it today brought back dim but interesting memories.

On the inside front cover of the hefty, as always, and impressive, light green, glossy journal was, just like today, a list of the Board of Governors (then known, more modestly, as Administrative Committee) and a list of the members of the Editorial Board. What jumped out at me was the fact there was a total of **four** (4) Associate Editors under the Editor-in-Chief. Today, by contrast, there are twenty-three (23). The Editor then was Carl Helstrom, a well-known luminary in the fields of Detection, Estimation, and Optical Communications. The Associate Editors were Tom Cover (yes, the same Tom Cover as today), W. Peterson, L. Kanal, and John Thomas. Tom was responsible for Book Reviews, Peterson was for Coding, Laveen for Pattern Recognition, and John for Stochastic Processes. Now isn't this a stunningly different view of the field compared to what it is today? We were indeed still in the formative years in 1968.

As for the AdCom, the Chairman (i.e., President) of the Group (remember we were a **group**, not a **Society**, then) was Bernard Elspas from the Stanford Research Institute. Then, there were two vice-chairmen, one for the "western district" (Andy Viterbi) and one for the "Eastern District" (Jim Massey). What an archane view of geographical coverage? The Secretary-Treasurer (still combined in a single entity) was K. Levitt. It's worth noting that both Viterbi and Massey were at the time up-and coming junior faculty at UCLA and Notre Dame respectively. The remaining members of the Board (sixteen in total) were A.V. Balakrishnan (known to his friends as "Bal"), J. Bussgang, L. Cutrona, Rudi Drenick, Bob Gallager, Sol Golomb, Carl Helstrom, D. Huffman (of Huffman Codes fame), W. Peterson, Bob Price, Bill Root, Len Schwartz, Mischa Schwartz, Dave Slepian, and J. Wozencraft. Quite a group, indeed!

Glancing at the contents, I noted that the first third of the magazine was devoted to a selected subset of the papers presented at the 1967 ISIT in San Remo the preceding September, some of which were in "abstract-only" form and others were in full-fledged journal format. They included a two-part series of generalizations of Reed-Muller Codes (the first part co-authored by our well-known colleagues Kasami, Lin, and Peterson) and the second part by E. Weldon. There were also papers by Dave Forney (Exponential Error Bounds for Erasure, List, and Decision Feedback Systems) and Elwyn Berlekamp (Nonbinary BCH Decoding). And there was a paper by Slepian (Group Codes for the Gaussian Channel).

The regular paper section included papers by Nelson Blachman (The Uncorrelated Output Components of a Nonlinearily), George Turin (The Effect of Weak Fading on the Output Spectrum of an FM System), Terry Fine (The Response of a Particular Nonlinear System with Feedback to Each of Two Random Processes), and Peter Schalkwijk (Center-of-Gravity Information Feedback). There were also papers on Sensor-Array Data Processing (F. Schweppe), Mismatched (!) Filter Response for Radar Clutter Discrimination (Stutt and Spaford) and Optimal Algorithmic Encoding Schemes for Information Sources (J.W. Snively, Jr.).

Then there was a true correspondence section containing two concise technical letters to the Editor, one on Optimum Thresholds for Binary Integration by R. Worley and one on Sequential Detection Without a Feedback Channel by A.V. Cameron.

The issue ended with a review of Minsky's book "Computation: Finite and Infinite Machines" by M. Arbib, a list of Books Received and the biographies of the contributors. It is interesting to note that every biography included the birthplace and birth date of the contributor, a practice that has been long abandoned.

Finally, on the inside back cover the editorial policy confirmed what was apparent from the sampling of the paper subjects that I highlighted, namely, that the appropriate topics for the journal included "the coding and decoding of digital and analog communication transmissions, studies of random interferences and of information bearing signals, analyses and design of communication and detection systems, pattern recognition, learning, automata, and other forms of information processing systems." In a way, the scope of the journal seemed to include communication theory, signal processing, coding, and a good deal of computer science.

This policy has been revised several times but the point remains that our Group (Society) was much broader than it is today. Should it have continued to embrace these diverse fields or did it do well to narrow its focus on the core? This is an interesting question to ponder.

On the back cover there was an unusual set of advertisements. Presaging the practice of the National Public Radio that permits subtle advertising through the careful choking of brief sponsor statements, the transaction had on its back cover what it called "Institutional Listings," namely,

organizations whose "assistance" to the field was acknowledge (for the modest fee of $50). On that issue the list was very short. It included "ADCOM, a Teledyne Company" of Cambridge, MA, and the "Cornell Aeronautical Laboratory" of Buffalo, NY.

This was indeed a very different time and a very different world. Nonetheless what has not changed is the "texture" of the work in our Society. Mr. Feerst (you all remember who he was) would still not know whether he was holding the Transactions upside down or not.

Obituary

On April 12, 2003, the information theory community was saddened by the loss of one its earliest and most beloved members, Sándor Csibi, who succumbed to heart disease at a hospital for cardiology in his home city of Budapest. Sándor suffered a severe heart attack two months ago, but typically this did not stop him from telephoning on February 17 from an intensive-care station to convey his congratulations to Ed van der Meulen, whose retirement at the Catholic University of Leuven was being celebrated that day. Sándor recuperated enough to be sent home for several days before he had to return again to the hospital for his final illness.

Sándor Csibi
1927–2003

Sándor began his research activity in 1951 at the Telecommunication Research Institute in Budapest, working in microwave communications. He later turned to pattern recognition and stochastic approximation. In 1973 he became Professor of Electrical Engineering at the Technical University of Budapest. By that time his main research interest had become multi-user communications. Although he retired officially in 1997, Sándor continued as an active researcher until his death. His research contributions were many and varied.

Sándor was a lifelong supporter of the field of information theory and information theory researchers. During the dark times of the Cold War he succeeded in maintaining close connection with colleagues throughout the world and brought many western researchers to Budapest. He also played a key role in attracting many talented young Hungarians into information theory. Sándor's presence there was the main reason for the choice of Budapest as the venue for the 1991 IEEE International Symposium on Information Theory. He served as Vice-Chairman of this very successful symposium.

Sándor was a Fellow of the IEEE. In 1979 and 1987 he was elected as a Corresponding Member and Ordinary Member of the Hungarian Academy of Sciences, respectively, both of which entitled him to use the prestigious title "Academician", a privilege he rarely used.

The many members of the Information Theory Society who knew him personally will remember Sándor as an affable man with a lively sense of humor and a true gentleman. Because his mother was a teacher of languages, Sándor grew up in a house where a different language was used at mealtime each day of the week. He made good use of this linguistic legacy in his contacts with friends and colleagues over the whole world.

Sándor is survived by his wife, Irene, by his two daughters, Eva and Susan, and by two grandchildren.

Letters to the Editor

Cancellation of the 2003 IEEE Information Theory Workshop, Hong Kong

Dear Members:

Due to the threat of an atypical pneumonia known as SARS (Severe Acute Respiratory Syndrome), the World Health Organization has issued a travel warning for Hong Kong and Guangdong (a province in South China). Since the situation is expected to continue for some time, we apologize and regret that we have to cancel the workshop.

It's a pity that we will not have the privilege to host you at this time. We hope to hold another workshop in Hong Kong when it becomes safe again.

Thank you for your support,

Victor Wei and Raymond Yeung
General Co-Chairs

Performance of Reduced-Rank Interference Suppression: Reflections and Open Problems

Michael L. Honig and Weimin Xiao

In this article we describe some of the background leading up to our paper on reduced-rank interference suppression [1], along with some related unsolved problems. This work has its origins in much of the work on multiuser detection and interference suppression for Code-Division Multiple Access systems, which had been in progress for more than a decade. At the time this work was in progress, subspace, or reduced-rank methods for interference suppression were being considered by a few different authors (e.g., [2-7]) as a way to reduce complexity, improve robustness, and reduce estimation error in an adaptive mode.

This paper was inspired by two prior important developments in the design and analysis of linear filters for interference suppression: (i) the introduction of the Multistage Wiener Filter (MSWF) [8,9], and (ii) the large system analysis of CDMA introduced in [10-12]. The first author was fortunate enough to listen to a conference presentation on the MSWF during the Milcom '97 conference [9]. Subsequently, work began on the application of this technique to CDMA. Initial simulation results demonstrated that the subspace dimension needed by the MSWF to achieve the full rank, or optimum (Minimum Mean Squared Error (MMSE)) performance was far below that required by other techniques being considered at the time, such as those which attempt to separate the signal and noise subspaces (e.g., Principle Components) [13, 14]. This served as the motivation for the subsequent large system analysis in [1].

MultiStage Wiener Filter

For the communications scenerio considered, the classical Wiener filtering problem is to estimate a transmitted symbol b_1, given a noisy N x 1 received vector

$$\mathbf{r} = \mathbf{S}\mathbf{b} + \mathbf{n}, \qquad (1)$$

where $\mathbf{b} = [b_1,....,b_k]'$ is the K x 1 vector of unit-variance transmitted symbols, $\mathbf{S}$ is an N x K signature matrix, and $\mathbf{n}$ is the noise vector with the covariance matrix $\sigma^2\mathbf{I}$. The optimal (full-rank) linear filter is given by the vector $\mathbf{c}$, which minimizes the Mean Squared Error $E\left[\left|\,|b_1 - \mathbf{c}^\dagger\mathbf{r}|\,\right|^2\right]$

A block diagram of a MSWF is shown in Figure 1. The filter consists of the constituent "sub-filter" $\mathbf{c}_1,...,\mathbf{c}_D$, the weights $w_1,...,w_D$, and the blocking matrices $\mathbf{B}_1,...,\mathbf{B}_{D-1}$. (In the figure D = 4.) Referring to Figure 1, the blocking matrices satisfy $\mathbf{B}_n^\dagger \mathbf{c}_n = 0$, for each n= 1,...,D - 1. The subfilter $\mathbf{c}_n$ has input $\mathbf{r}_{n-1}$ and output d_n (i.e., d_n=$\mathbf{c}_n^\dagger \mathbf{r}_{n-1}$). Futhermore, $\mathbf{c}_n$=$E[d_{n-1}^* \mathbf{r}_{n-1}]$(possibly normalized so that $\|\mathbf{c}_n\| = 1$), and can be interpreted as a matched filter for estimating d_{n-1} from $\mathbf{r}_{n-1}$.

The MSWF essentially decomposes the original estimation problem, i.e., estimate $d_0 = b_1$ from $\mathbf{r}_0 = \mathbf{r}$, into a sequence of subproblems, i.e., estimate d_n from $\mathbf{r}_n$ for n-1,...,D-1. At any stage n, if $\mathbf{c}_n$ is optimal (i.e., minimizes $E\left[\left|d_{n-1} - \mathbf{c}_n^\dagger \mathbf{r}_{n-1}\right|^2\right]$), then the associated truncated filter at stage n, is equivalent to the full-rank MMSE filter. For example, if $\mathbf{c}_2$ is replaced by the associated MMSE filter, then the truncated filter consisting of $\mathbf{c}_1$, $\mathbf{B}_1$, $\mathbf{c}_2$, w_1 and w_2 is the classical generalized sidelobe canceller [15]. The MSWF is obtained by recursively expanding each subfilter according to the generalized sidelobe canceller structure. Truncating the filter to D stages corresponds to projecting the full-rank solution onto D-dimensional subspace, and is a *reduced-rank* MSWF.

The reduced-rank MSWF has an appealing, regular structure, which intriqued the authors. Furthermore, it has relatively low complexity. Namely, adaptive versions of the MSWF require less computation than other reduced-rank techniques, which require an eigen-decomposition of the input covariance matrix [13, 14]. This motivated the desire to obtain a deeper understanding of its structure and performance.

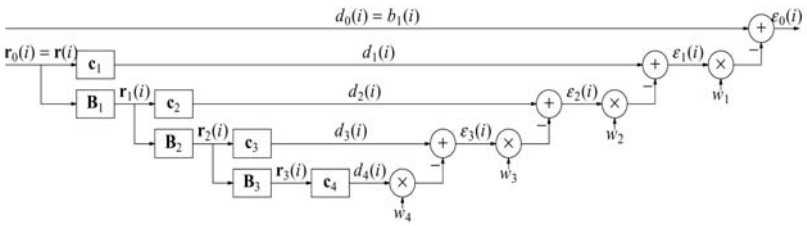


Figure 1: Multi-Stage Wiener Filter.

Editor's Note: The paper "Performance of reduced-rank linear interference suppression," by Michael L. Honig and Weimin Xiao, which appeared in the July 2001 IEEE Transactions on Information Theory, was awarded the 2002 Commmunications Society / Information Theory Society Joint Paper Award. This invited paper is the authors' reflections on their prize winning paper.

Large System Performance

In applications such as CDMA and multi-antenna systems, the mixing matrix **S** in the model (2) is typically random, which complicates the performance evaluation. Namely, it is generally difficult to evaluate the output Signal-to-Interference-Plus-Noise Ratio (SINR) averaged over **S**. Interestingly, if the elements of **S** are i.i.d., then a closed-form expression for the SINR can be obtained by letting K and N tend to infinity with fixed ratio $\alpha=K/N$.

The authors first became aware of this type of large system analysis for CDMA through the conference presentation [16]. This has proven to be a very powerful technique, and has been used by numerous authors in recent years to analyze the performance of various receivers with different types of Multi-Input/Multi-Output channels. For the linear estimation problem considered, Tse and Hanly [12] showed that the output SINR for the full-rank linear receiver (β) satisfies the fixed point equation

$$\beta = \frac{1}{\sigma^2 + \alpha \frac{1}{1+\beta}} \qquad (2)$$

(Here we assume that each element of **S** has mean zero and variance $1/N$.)

We began our large system analysis of the MSWF rank by rank. Namely, if the rank D=1, the MSWF is simply a matched filterwith large system SINR $\beta_1 = 1/(\alpha+\sigma^2)$. We obtained expressions for the SINR corresponding to $D = 2$ and $D = 3$ as well, but going beyond this seemed exceedingly tedious and messy. The expression in the paper was obtained by a good guess. Namely, we observed that the Tse-Hanly formula can be written as the continued fraction

$$\beta = 1/(\sigma^2 + \alpha/(1+1/(\sigma^2+\alpha/(1+\ldots)))) \qquad (3)$$

Because of the regular, iterative structure of the MSWF, we suspected that the SINR as a function of rank D might be obtained by simply truncating this continued fraction. It was easy to verify numerically that this is indeed true. Proving it, however, was more challenging than we expected, and was accomplished over a period of a few months.

It occured to us after we guessed the expression for reduced-rank SINR that essentially full-rank performance can be obtained with a finite-rank MSWF, independent of the system size (K and N). That is, the preceding continued-fraction converges in about eight iterations, corresponding to D = 8, no matter how large K and N are. This came as a big surprise, since all other subspace techniques we knew of, such as those which try to separate the signal and noise subspaces, require the subspace dimension D to grow with K and N to achieve full-rank performance. Therefore, the MSWF has the advantage that for a given application, the rank can be bounded *a priori*, independent of the number of users, or data sources. The paper also evaluates the large system performance of other reduced-rank techniques by letting $(D, K, N) \to \infty$ with D/K and K/N fixed. As with prior large system analyses, the results accurately predict the performance of moderately sized systems (e.g., $N \geq 16$).

Open Problems

Our analysis of reduced-rank filters leads to some related mathematical problems, which we briefly describe. It is shown in [1] that the rank-D MSWF is the linear filter, which minimizes the output MSE subject to the constraint that the filter lies in the D-dimensional Krylov subspace spanned by the columns of $\mathbf{S}_D = [\mathbf{s}_1\ \mathbf{R}\mathbf{s}_1\ \mathbf{R}^2\mathbf{s}_1 \ldots \mathbf{R}^{D-1}\mathbf{s}_1]$, where $\mathbf{R} = E[\mathbf{r}\mathbf{r}^\dagger]$ is the input covariance matrix.[1]

Using this representation leads to an alternative expression for the large system output SINR in terms of the large system moments of **R**. (See Theorem 3 in [1].) A direct derivation of the continued fraction formula from the large system moments of **R** has not yet been obtained. More importantly, the expression for SINR in terms of the moments of **R** applies to more general scenarios, e.g., with arbitrary powers (i.e., the mixing matrix **S** is replaced by $|\mathbf{A}|^2\mathbf{S}$ where **A** is diagonal), and multiple antennas. Generalization of the continued-fraction expression for SINR to these more general scenarios (if possible) remains an open problem. (Some progress in this direction is made in [20].)

Another problem is related to the equalization application. The model (1) again applies where **S** is Toeplitz. In that case, the "large system" output MSE corresponds to letting the filter length tend to infinity, and can be expressed in terms of the channel moments $\int_{-1/2}^{1/2} |H(e^{j2\pi f})|^{2n}\, df, n = 1, \ldots, D$, where $H(e^{j2\pi f})$ is the channel transfer function [21]. As D increases, the MSE must converge to the full-rank MMSE, given by the well-known expression

$$\int_{-1/2}^{1/2} \frac{\sigma^2}{\sigma^2 + |H(e^{j2\pi f})|^2} df.$$

Analogous to the CDMA case, there is likely to be an expansion of the preceding expression, which corresponds to the performance of the reduced-rank MSWF.

A more fundamental problem is the performance of *adaptive* reduced-rank filters with finite training. That is, one of the main motivations for reduced-rank, as opposed to full-rank filtering, is that it can provide better filter estimates when training is limited. For the ideal model (2), the theory of large random matrices can again be used to evaluate large system performance, and illustrates the effect of rank selection, initialization, and data windowing on performance [22].

A related question is whether or not the performance of the adaptive MSWF with limited training is optimal in some

[1] Related filters, which are constrained to lie in a Krylov susbspace, have been proposed in [3,17-19].

meaningful sense. This appears to be largely unanswered. The large system analytical approach may again provide insight.

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Channel Uncertainty in Communications

Continued from page 1

and measurement [Rap01]. Our aim is to provide some discussion of the effects of the channel uncertainty on the applicability of information theoretic results in practical systems. Our bibliography will remain intentionally scant and omit many important results, for the benefit of simplicity. Many issues besides channel uncertainty affect the migration from theory to practice: computational complexity and its attendant implementation challenges; regulatory constraints prescribing use of bandwidth and power; the prevalence of standards which limit flexibility to enable harmonious co-existence of users, economies of scale and positive network effects. Yet, channel uncertainty remains a fundamental issue, one that may be alleviated but not altogether obviated by progress in computational power, or by regulatory and standards' flexibility. We concentrate on the three types of uncertainty mentioned above, due to channel measurement error, network operating conditions and channel modelling.

The first type of uncertainty, that associated with channel measurement error, immediately affects receivers. The effect of channel error is that of multiplicative noise in the channel. Transmissions are therefore simultaneously conveying data and providing a sounding of the channel. However, these dual roles for transmission lead to very difficult design issues. If our goal were to measure the channel, then we would wish to sound the channel with a constant and known signal. Transmission of information, on the other hand, requires highly variable transmissions to reflect the randomness of the data. This tension between signaling for measurement purposes and signaling for transmission purposes is generally resolved by decoupling the two, generally by pilot-symbol assisted modulation (PSAM), in which pilot symbols are regularly interspersed in the transmission of data. Measurement is artificially circumscribed to received pilot symbols, and transmission is designed to the level of accuracy in channel measurement afforded by the pilot symbols. The deleterious effects of channel uncertainty directly impact system design. The allocation of energy and time to channel measurement depends crucially on the benefits that more accurate measurements yield. In a channel that varies sufficiently rapidly, measurement attempts may be futile, or may be only very coarse, since the variations are too rapid to allow simultaneously for accurate channel tracking and adequate resources for transmission.

Channel uncertainty at the receiver also affects feedback. Whatever uncertainty regarding the channel may exist at the receiver is exacerbated by feedback. The feedback may be delayed, noisy, or limited in energy and bandwidth. The role of channel information at the transmitter may be viewed as being even more complex than that at the receiver. The transmitter must incorporate explicitly the effect of channel information at the receiver into the use it makes of the channel information. The receiver may change its rate, transmit energy and modulation in response to the channel state information (CSI) it culls from feedback and possibly other sources, such as out-of-band pilots. Note that our use of the term CSI does not entail a specific finite-state model in our discussion. Uncertainty in CSI at the sender may potentially have more effects on system performance than channel error at the receiver. While channel error at the receiver may lead to errors and possibly error propagation, channel error at the transmitter may compound. An inaccurately high estimate of SNR, for instance, may lead to a reduction in transmitted energy, which will worsen the channel estimate. The stability of power control under uncertain channel measurements, with explicit accounting for the effect of power control on channel measurement, is a difficult topic. The general approach in the literature has been to assume some channel side information at the sender and consider a particular relationship between the channel and receiver CSI.

In practice, the transmitter does not take CSI into account in a detailed fashion and hence practical systems avail themselves very incompletely of the wide array of tools of information theory. For instance, although wireless channels suffer from inter symbol interference (ISI) due to multipath phenomena, traditional water-filling techniques are not generally used. These techniques are well understood when a detailed description of the channel impulse response is known. Beyond issues of system complexity, significant issues of channel uncertainty emerge when we consider ISI channels. The first issue concerns the robustness of water-filling techniques to channel error. The other, related, issue, concerns the cost, in terms of feedback bandwidth, of providing sufficiently accurate channel estimates. The cost of feedback must be weighed against the benefit derived from such feedback. While feedback is in general in the information-theoretic literature assumed to be free, and often error-free, the resources devoted to feedback are not free. The benefit of feedback lies mainly in the information it yields about CSI. Thus, the effect of channel uncertainty directly affects the transition of such standard information-theoretic tools as water-filling into practice.

Channel measurement uncertainty affects considerably the development and deployment of new wireless systems. The most desirable wireless spectrum real estate, dedicated bands at moderately low carrier frequencies (below 1 GHz), is generally scant. In order to extend wireless services, two main approaches have emerged. One is to use bands that may be at high carrier frequencies, which suffer from faster fades and higher losses. Moreover, these bands may be unlicensed, that is, shared by many services without the pro-

tection of exclusive use afforded by licenses. The other main approach is to use very large contiguous bands. This approach, often termed ultrawideband, requires new services to overlap with existing services over licensed bands.

The first approach, that of using channels in a high carrier frequency regime, entails rapid change of channels, since the rate of change of channels, generally indicated by Doppler spread in wireless channels, is proportional to carrier frequency. Channel uncertainty in this regime may be significantly aggravated by the rate of change of the channel. Moreover, the cost and, hence, the benefit of providing sender CSI via feedback, may be also be greatly affected. Common assumptions about channel behavior, such as underspread conditions, in which time spread is far smaller than coherence time, become gradually less valid as the carrier frequency increases. The effect of channel uncertainty may then become more pernicious than before. For instance, the ISI profile may experience change within a single time spread. Such channel uncertainty may require different models than the ones used for underspread channels.

Rather than transmit at high carrier frequencies alone, we may use a very large range of frequencies, a scheme commonly referred to as ultrawideband. While ultrawideband in the current regulatory environment in effect assumes a particular family of signaling schemes, we shall use the term ultrawideband to refer to services that use considerably more spectrum than even traditional spread-spectrum systems, and which may co-exist with other services over some or all of the bandwidth they use. The first capacity results in this area date back to the 1960s [Ken69] and have received considerable attention recently [ET]. These results indicate that, in the infinite bandwidth regime, for channels that decorrelate in time and frequency, CSI at the receiver is useless. However, these limiting results hide significant effects at even very large bandwidths. In the absence of CSI at the receiver, capacity is approached arbitrarily slowly with bandwidth [Ver02], and error exponents grow very slowly with bandwidth [LMAF02]. Moreover, the peak energy of these schemes becomes extremely large, posing severe difficulties for implementing them safely. If, instead, spreading schemes such as traditional direct-sequence code-division multiple access are extended to large bandwidths, then channel measurement again becomes very significant. In such types of spreading schemes, all degrees of freedom are used concurrently. The ensuing low energy per degree of freedom entails very poor channel estimation, which eventually leads to the inability to detect the transmission itself and vanishing overall capacity. Other schemes proposed for ultrawideband systems use pulse position modulation and variants thereof. Again, channel measurement uncertainty imputes certain limits on such schemes. In particular, for an unknown channel, pulses within a time spread of each other may be indistinguishable. Thus, the uncertainty in the channel leads to a limit on the rate that can be transmitted, to a first order approximation, as the inverse of the time spread. Without channel measurement, channel uncertainty may thus lead to a practical limit on the usefulness of extra bandwidth.

Note that the issues of feedback that we mentioned previously are exacerbated in ultrawideband channels. In particular, limiting results with feedback may lead to rather strange conclusions. If we were able to perform water-filling over a known channel with infinite bandwidth, then we could, with infinitesimal energy, achieve infinitely large capacity by transmitting all of our energy over a single coherence band with infinite energy. The occurrence of such a band becomes asymptotically certain as the total bandwidth grows. Of course, we would never obtain perfect CSI at the the transmitter, or infinite bandwidth over which to transmit. Indeed, measurement of the channel over the entire bandwidth to any prescribed level of accuracy would require infinite energy. This example further illustrates how issues of channel uncertainty are complicated by considering asymptotic regimes.

Another apparent paradox of the asymptotic regimes is that, in the infinite bandwidth regime, multiple access interference is non-existent. Indeed, each user can be granted its own infinitely large spectrum and thus interference may be altogether avoided without, seemingly, any cost. Again, asymptotically, CSI at the receiver does not affect the multiple access capacity. In the finite bandwidth regime, however, receiver CSI does affect capacity for multiple access channels. The multiplicative noise effects present in single-user channels remain. Moreover, imperfect channel information affects interference cancellation. Interference cancellation among users achieves corner points of the Cover-Wyner region. Since interference cancellation entails subtraction of decoded users' contribution to the received signal, it is inherently a coherent process. Imperfect knowledge of the phase may therefore render such interference cancellation inaccurate and may even induce error propagation among users.

Multiple access scenarios often occur not only over a single shared channel, but in the context of networked systems. Channel uncertainty is then inextricably linked with operating conditions in networked applications. The interplay between networking and information theory is difficult [EH98]. We seek only to highlight a few issues associated with this interplay. Operating conditions in networks include the number of users present in a wireless system and the burstiness of their data streams. Such conditions affect multi-user interference over shared wireless channels, for instance. Moreover, in wireless networks, issues unrelated to the wireless interface may affect the use of the channel. In packetized data systems, loss of packets may also be due to such issues as router loading and ensuing loss of data through buffer overflow or flow control methods such as random early discard. In this case, channel uncertainty regarding physical conditions, such as impulse response or interference, combines with the randomness due to the operation of protocols over possibly complex networks. If most of the feedback is provided through protocols, it may be difficult to assess whether loss of a packet was due to poor signal to noise ratio related to fades, or to high interference, or to loading at a router. The use of long codewords, which is desirable to average the behavior of a channel and approach capacity,

may not be compatible with the transmission of packetized data. Indeed, in common windowing systems such as Transmission Control Protocol (TCP), excessive delay is used to infer congestion and triggers window closing, i.e., a rapid reduction in transmission rate, from which a user emerges by gradual increase of its rate. The delay due to coding may be inaccurately perceived, by protocols unaware of the wireless physical layer, as delay associated with heavy loading. Heuristics to alleviate the tension between long delays for effective channel coding and the use of delay as a network probing mechanisms are numerous and varied. Some include actually transmitting in effect fictitious acknowledgements to placate the need for low delay. This may increase channel uncertainty, by introducing possibly inaccurate feedback. If channel information is being inferred from the feedback provided by protocols, erroneous estimates of CSI may be produced. Moreover, if adaptive measures, such as increasing or decreasing data rates, are undertaken in response to even accurate CSI, it may lead to unknown effects in the network, possibly by affecting congestion.

Inferring CSI from feedback may not only be difficult because of the interactions associated with network operating conditions and protocols. Even if these interactions were to be resolved harmoniously, or if we were to restrict ourselves solely to point-to-point transmissions, the meaning of CSI is heavily dependent on the type of model used for channels. For tractability, channel models used in information-theoretic settings are necessarily simple. Fading is generally assumed to occur in leaps in time and/or frequency. As the simplest level, channels are assumed to be static over a block in time and/or frequency, and to evolve independently from block to block. The tractability of these models is appealing and useful. However, channel decorrelation may be very complex. Even in the literature dealing with channel modelling, the meaning of coherence time is not uniformly accepted. Certain authors consider that a correlation of about one third indicates decorrelation, whereas others require about one tenth. Variations may be more gradual than block-to-block independence. Common models include finite-state Markov channels. Continuous models are few and necessarily simple, such as Gauss-Markov channels.

Not only is the evolution over time or frequency of channels highly simplified, but generally few models for statistics of channels are also used. Common models involve Gaussian statistics not only for the noise, but also for the impulse response. The justification for such models follows the usual limiting arguments of the Central Limit Theorem. The resulting models are thus Gaussian with zero mean, implying a Rayleigh amplitude, or non-zero mean, implying a Rician amplitude. A generalization of Rayleigh and Rician is the Nagakami model. It is not clear whether the channel model is inherently accurate or merely useful because of the extra degrees of freedom it affords, in effect providing a splining tool. Whatever model is chosen to represent the time variations and the distribution of the channel parameter, it will generally be fairly simple. While such simplicity is useful in extracting the essence of the random and time-varying nature of the channels, the sensitivity of capacity-achieving coding schemes to channel model accuracy is seldom investigated. To some extent, the care and mathematical precision with which capacity-achieving schemes are derived for many channel models belie the coarseness of the underlying channel model. As illustrated in our discussion on ultrawideband channels, models or assumptions about channel knowledge may lead to extreme and possibly incongruous conclusions, particularly when asymptotic regimes are considered. Channel modelling errors may impute no less performance loss than measurement error. Modelling errors may not be inherently untractable - a simple approach may involve compound channels. However, the characterization of the modelling error, and the interplay between modelling error and other related phenomena, such as channel measurement error, power control policies and coding strategies, appears to be complex in general. The ability to bound the effect of channel error may at least afford some measure of confidence in the applicability of capacity results to real systems.

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IT Members Elected to the Grade of Fellow

The following IT Society members were elected the grade of Fellow and sponsored by the IT Society.

Dr. Torleiv Kløve C, IT **IT**
University of Bergen
for contributions to coding theory and error-detecting codes.

Prof. Kingo Kobayashi IT **IT**
The University of Electro-Communications
for contributions to the theory of finitary information systems.

Dr. Vladimir I. Levenshtein IT **IT**
Staraya Basmannaya Str., 22-68
for contributions to the theory of error correcting codes.

Dr. Ueli M. Maurer C, IT **IT**
Swiss Federal Institute of Technology
for contributions to the theory and practice of cryptography.

Prof. Joseph Andrew O'Sullivan CAS, COMM, **IT**
Washington University CS, IT, SP
for contributions to information-theoretic imaging with applications to medical tomographic systems and radar imaging.

Dr. Ron M. Roth **IT** **IT**
Israel Institute of Technology
for contributions to algebraic and modulation coding.

Dr. Raymond W. Yeung COMM, IT, VT **IT**
The Chinese University of Hong Kong
for contributions to network coding theory.

The following IT Society members were elected to the grade of Fellow.

Prof. Yuval Bistritz CAS, COMM, **CAS**
Tel Aviv University IT, SP
for contributions to the stability theory of multi-dimensional linear systems and applications to estimation and interpolation problems.

The following members of the IT Society were elected to the grade of Fellow.

Dr. Rene L. Cruz **IT** **COMM**
University of California, San Diego
for the development of a network calculus for characterization of traffic on packet networks.

Prof. Rolf Ernst AES, BT, C, CAS, CE, COMM, Ed, **C**
GRS, IE, IM, IT, PC, R, SP, SSC, VT
Technical University of Braunschweig
for contributions to the design automation of co-design hardware and software embedded systems

Dr. Hironori Hirata C, IT, SMC **SMC**
Chiba-University
for contributions to the research and development of modeling, analysis, and optimization methods for large-scale systems.

Prof. Khaled Ben Letaief COMM, IT, VT **COMM**
Hong Kong University of Science & Technology
for contributions to the analysis, design, and performance evaluation of high-speed wireless communication systems.

Dr. Thomas Louis Marzetta IT, SP **SP**
Bell Laboratories, Lucent Technologies
for contributions to the theory of multidimensional signal processing and multiple-antenna communications.

Mr. John Jacob Metzner C, COMM, **COMM**
IT, VT
Pennsylvania State University
for contributions to reliable data communications.

Dr. Takehiro Moriya COMM, IT, SP **SP**
NTT Cyber Space Laboratories
for contributions to speech compression and audio coding technologies and their standardization.

Prof. Pierre Moulin IT, SP **SP**
University of Illinois
for contributions to statistical signal processing and the theory of information hiding.

Prof. Kenneth Rose COMM, IT, SP **SP**
University of California
for contributions to information-theoretic methods in signal processing.

Prof. Peter Kingsford Willett IT, SP **AES**
University of Connecticut
for contributions to detection, target tracking, and signal processing.

Information Theory Society Board of Governors Minutes

Hotel Windsor Sheraton, Bangalore, India, October 21, 2002

Aaron Gulliver

Attendees: Vijay Bhargava, Tom Cover, Anthony Ephremides, David Forney, Marc Fossorier, Tom Fuja, Aaron Gulliver, Bruce Hajek, Hideki Imai, Torleiv Kløve, Jim Massey, David Neuhoff, Vinod Sharma, Sergio Verdú, Raymond Yeung

1. The meeting was called to order at 7:00 PM by Society President Tom Fuja. Those present were welcomed and introduced themselves. The Agenda was approved as distributed.

2. The minutes of the annual meeting held in Lausanne, Switzerland on June 30, 2002, were approved with amendments.

3. Society President Tom Fuja began with an update on the financial situation of both IEEE and the IT Society. The IEEE deficits for 2002 may be less than projected due to IEEE cost savings. However, the infrastructure charges to the society will deplete assets in a very short time. The society has no means of balancing the budget for 2003, and it is not clear how this can be done in 2004.

   The IEEE assessments are based on a formula which includes membership and activities. This ensures that the societies pay for the services that are used. The audit of the IEEE currently being undertaken will examine the method by which these charges are calculated. He noted that IEEE dues do not even cover staff salaries. IEEE staff numbers and salaries were discussed. Charges are made by IEEE to support/update services such as IEEE Xplore (IEL). There was some discussion on the All Societies Periodical Package (ASPP) income distribution as it is the biggest source of funds for the society. The question of whether IEL will be able to sustain the society as ASPP revenues decline was also discussed. At this point it was stated that the Ad-Hoc Committee on Secession has focussed its deliberations on publications. The committee report is summarized in item 5.

   There are currently nine IEEE societies without a balanced budget. Many IEEE societies (such as communications) derive a large portion of their revenues from conferences. It was stated that membership dues are still low considering the member benefits, and the loss in members due to doubling dues from $15 to $30 was only about 100. Dues increases should be gradual to minimize these losses. An Ad-Hoc Committee on Survival was established to devise a balanced budget for 2004 and prepare a survival plan and options to be presented at the next board meeting. The committee consists of Han Vinck, Tom Fuja, Hideki Imai, Marc Fossorier and Steven McLaughlin. It will consider issues such as membership dues and Transactions charges and delivery. At present, most societies charge extra for Transactions.

   President Fuja stated that the Division X Director was invited to attend a board meeting, but has thus far never attended a meeting. The board felt that the Technical Directors do not support the societies, and IEEE has established a corporate culture which is focussed on profit making. In summary, there are two major issues, financial survival of the society and IEEE reform.

4. Marc Fossorier presented the Treasurer's Report. He distributed an overview of the current financial status of the society, including a chart of the total assets of the society which shows that current reserves have declined to $705,000. IEEE charges for 2002 amounted to $40,800 for infrastructure, $150,100 for corporate recovery and $69,100 for ASPP recovery (total $270,000). In addition, there was a $53,300 charge for TAB support. A deficit of $233,000 is budgeted for 2002 as a result of these charges. The charges for 2003 will be $205,000 plus $40,800 for TAB support. At present a society deficit of $185,600 is projected. The charges for 2004 will be similar, which will deplete society assets unless there is a significant change in society finances.

   The financial status of recent and pending conferences was also presented.

5. The report from the Ad-Hoc Committee on Secession was discussed next. Three topics were considered by the committee.

   (a) Forming a 'Friends' organization to meet the needs of the IT community and/or provide a more financially viable organization.

   (b) Joining forces with another society to gain better bargaining power with IEEE (this is the likely IEEE solution if the society's funds are depleted).

   (c) Keep the status quo and revamp the current financial structure so as to make the budget balanced.

   The report also stated that the goals of the IEEE and the IT Society are diverging, the members want the publications without the large IEEE corporate infrastructure. The question of why bother with the Transactions if it does not generate revenue for the society was raised. The committee will continue to work on these topics and in particular on the important issue of publications.

6. The Transactions Report prepared by Editor-in-Chief Paul Siegel was distributed and discussed. The Transactions continues to have no backlog, and to be mailed on time. The Final Call for Papers for the 2003 Special Issue appeared in the October 2002 issue of the Transactions and the December 2002 issue of the Newsletter.

The first Call for the 2004 Special Issue will be published in the November 2002 issue of the Transactions and the December 2002 issue of the Newsletter.

Four new appointments to the Editorial Board were presented to the Board for approval:

(a) Nonparametric Estimation, Classification and Neural Networks: Andrew Nobel replacing Gabor Lugosi, effective September 1, 2002.

(b) Quantum Information Theory: Emanuel Knill replacing Peter Shor, effective October 1, 2002.

(c) Sequences: Kenny Paterson replacing Andrew Klapper, effective December 1, 2002.

(d) Shannon Theory: Raymond Yeung replacing Prakash Narayan, effective January 1, 2003.

The appointments were approved unanimously.

The 2003 final estimated page budget is 3420. It was noted that the number of pages has risen steadily over the years, and a suggestion was made that the scope of the Transactions be revised. The estimated costs for using a remailer to reduce mailing times in Regions 8 to 10 was confirmed to be $ 2,900. Thus the Board decision to use a remailer in this capacity was conveyed to IEEE Publishing. It was suggested that the page numbers for the Transactions be adjusted to minimize this additional cost, this will be brought to the attention of the Editor-in-Chief.

Despite objections by several Editors-in-Chief of IEEE Transactions (including IT Transactions), and President Tom Fuja, the IEEE Publications Services and Products Board voted to implement a reduced trim size for IEEE journals. In addition, they voted to reduce the weight of the paper used to print the journals from 40- to 36-pound stock.

The introduction of a new letters journal was discussed. Feedback from Des Taylor, Editor-in-Chief of Communications Letters, indicates that the number of submissions to this journal is high, and the reason the issues are small is because of the page budget. The financial implications of such a move were discussed, and it was felt that this is not the right time to introduce a new IT Society publication.

7. Aaron Gulliver presented the report on the IT Society website. The new website developed by IEEE Entity Creation Services has been finalized and should be online by the end of the year. There is a link on the old website to the test version of the new website, and the board members were encouraged to review it. Along with the new website, an IT Forum is being set up to allow discussions on issues that affect information theory and the society. This was an initiative of Han Vinck. The website statistics for the year 2002 (to date) were presented. There were no significant changes since the Lausanne meeting report. Of the 108 countries which have accessed the website, the top ones in terms of activity are: US, Japan, Canada, Germany, UK, France, Italy and Australia.

The following Newsletter download activity was also presented.

Issue	**Hits**
September 2002	325
June 2002	709
March 2002	1098
December 2001	1624

It was noted that the September Newsletter was only recently posted.

Finally, web pages devoted to Claude Shannon have had over 1500 hits this year. He will be featured on the home page of the new website.

8. Vijay Bhargava presented the report of the Fellows Nomination Committee, which consists of Vijay Bhargava, Joachim Hagenauer and Ian Blake. The 2003 Fellow Committee will be Costas Georghiades (Chair), Tony Ephremides, Ed Vander Meulen, Shlomo Shamai and Ezio Biglieri.

9. A Bylaw change to establish the Distinguished Service Award was presented by Vijay Bhargava. The scope, wording and honorarium were discussed, but no changes were made. Voting to approve the amendment will be done at the next board meeting.

10. Tom Fuja presented the report from the Ad-Hoc Committee on Frequency of ISITs. Two proposals were generated by the committee, one for yearly symposia, and one for two-out-of-three year symposia. The two major concerns are the potentially larger number of attendees for two-out-of-three year symposia and the short submission deadlines with yearly symposia. Statistics were presented that show there has been an increase in attendees despite the move to yearly symposia. The discussion centered on the quality of submissions and reviews. It was suggested that quality could be improved by increasing the number of reviewers and the rigor of the reviews. However, this will require more time and resources.

It was noted that the referendum ballot held at ISIT 2002 produced 66% in favor of the two-out-of-three year frequency, while only 33 % voted in favor of yearly symposia.

The board decided that no changes will be made in ISIT frequency at this time.

11. The reports on Symposia and Workshops were presented next.

11.1. Jim Massey reported on ISIT 2002. Finances have not been finalized, but a surplus of 60,000 SFR is projected. The organizers received lots of feedback on the venue, computer access, etc., the only negative comments were on the banquet (which ran out of food), and the hotels (which were widely separated). A motion to provide 6,500 SFR to support the Winter School on Information Theory in Switzerland was approved unanimously. A motion to provide half of the ISIT 2002 surplus to the organizers to support IT activities in Region 8 was defeated.

11.2. Tom Fuja presented the report on the 2002 Information Theory Workshop. Attendance is 62 from outside India and 115 from inside. The large number of Indian delegates will not have a serious effect on the budget.

11.3. Marc Fossorier reported on the report on the 2003 Information Theory Workshop to be held in Paris, France. A bank account has been set up and a management society hired. ENST will produce the proceedings, the banquet will be held at the Musée d'Orsay and the reception at ENST.

11.4. Hideki Imai reported on the progress of ISIT 2003, to be held in Yokohama, Japan. The plenary speakers have accepted their invitations and the Wednesday afternoon excursion has been arranged.

11.5 Raymond Yeung presented a report on the Information Theory Workshop to be held in Hong Kong July 6-10, 2003. The preliminary Call for Papers is out and the venue has been selected. The organizers are in the process of choosing the session chairs.

11.6. Bruce Hajek presented the report on the 2004 Information Theory Symposium to be held in Chicago, IL. The Call for Papers has been distributed, the deadline for submissions is December 1. The plan is to have tutorials as was done at ISIT 2000 in Sorrento. The organizers are currently looking for a banquet venue.

11.7. There was no report on ISIT 2005 to be held in Adelaide, Australia.

12. Under new business, Senior Past-President Vijay Bhargava thanked the Board for its support during his five years on the executive.

13. The next board meeting will be held at a time and place to be determined by the incoming president, Han Vinck. Tom Fuja thanked the organizers of the workshop for making arrangements for the Board Meeting. The meeting was adjourned at 9:45 PM.

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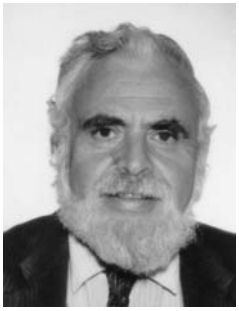

A Latin Square of order n is an n x n array of n symbols (we will use 1, 2, . . . , n as the symbols), such that each symbol occurs once in each row and once in each column.

A Latin Square of order n is in standard form if the top row and the left-most column each contain the symbols $1, 2, \ldots, n$ in sequential order.

A transversal of a Latin Square of order n is a set of n of the positions ("cells") of the square with one in each row, one in each column, and containing each of the n entries exactly once.

Here is an example of a Latin Square of order 5 in standard form in which the members of a transversal are circled.

1	(2)	3	4	5
2	5	1	(3)	4
3	4	(5)	1	2
(4)	1	2	5	3
5	3	4	2	(1)

The "multiplication table" (or "Cayley table") of a finite group is always a Latin Square; but Latin Squares, in general, are not "group tables". (They can be viewed as quasi-groups, which lack the associative law of groups, and are far more numerous than groups, as a function of the order n.)

Two Latin Squares of order n (not necessarily in standard form) are called orthogonal if the n^2 ordered pairs of corresponding elements are all distinct. An example with $n = 3$ is:

1	2	3
2	3	1
3	1	2

,

1	2	3
3	1	2
2	3	1

with ordered pairs

11	22	33
23	31	12
32	13	21

.

Try to prove each of the following results.

1. If L is a Latin Square of order n, there is a second Latin Square L' of order n orthogonal to L if and only if L has n disjoint transversals.

2. If L is the "Cayley table" of a group of order n, then there is a second Latin Square L' of order n orthogonal to L if and only if L has (at least) one transversal.

3. If $p = n + 1$ is prime, $n > 1$, then the multiplicative group modulo p, viewed (from its Cayley table) as a Latin Square of order n, has no transversals.

4. The number of Latin Squares of order n such that any two of them are orthogonal cannot exceed n - 1. ("The maximum number of Mutually Orthogonal Latin Squares – MOLS – of order n cannot exceed n - 1.")

5. If a Latin Square of order n has n - 1 disjoint transversals, then it has n disjoint transversals (and therefore, in view of 1., an "orthogonal mate").

Euler conjectured, and it was eventually proved, that a pair of orthogonal Latin Squares of order 6 does not exist.

6. Find a Latin Square of order 6 with 4 disjoint transversals.

GOLOMB'S PUZZLE COLUMN ™
FACTS ABOUT $\binom{2n}{n}$ SOLUTIONS

1. a. $\binom{2n}{n} = \frac{2n}{n}\cdot\frac{2n-1}{n-1}\cdot\frac{2n-2}{n-2}\cdots\frac{n+2}{2}\cdot\frac{n+1}{1} > 2\cdot 2\cdots 2 = 2^n$ if $n > 1$.

$4^n = (1+1)^{2n} = 1 + \binom{2n}{1} + \cdots + \binom{2n}{2n-1} + 1 > \binom{2n}{n}$ if $n > 0$.

b. From Stirling's Formula, $n! \sim \sqrt{2\pi n}\left(\frac{n}{e}\right)^n$ as $n \to \infty$, we get

$$\binom{2n}{n} = \frac{(2n)!}{(n!)^2} \sim \frac{\sqrt{4\pi n}}{2\pi n}\frac{(2n)^{2n}}{n^{2n}} = \frac{1}{\sqrt{\pi n}}4^n \text{ as } n \to \infty.$$

2. a. $\binom{2n}{n}$ is the number of ways to select a subset of n objects from a set of $2n$ (distinguishable) objects. If we arbitrarily partition the $2n$-set into two n-sets, we can select n objects from the original $2n$-set by selecting k objects from the first n-set and the remaining $n-k$ objects from the second n-set, for each value of k, $0 \le k \le n$. Thus, $\binom{2n}{n} = \sum_{k=0}^{n}\binom{n}{k}\binom{n}{n-k} = \sum_{k=0}^{n}\binom{n}{k}^2$.

b. From $(1-t^2)^m = (1+t)^m(1-t)^m$ we have the binomial expansions $\sum_{k=0}^{m}(-1)^k\binom{m}{k}t^{2k} = \sum_{i=0}^{m}\binom{m}{i}t^i\sum_{j=0}^{m}(-1)^j\binom{m}{j}t^j$. When $m = 2n$, the coefficient of $t^m = t^{2n}$ on the left (at $k = n$) is $(-1)^n\binom{2n}{n}$, while the coefficient of t^{2n} on the right is the convolution

$\sum_{k=0}^{m}(-1)^k\binom{m}{k}\binom{m}{m-k} = \sum_{k=0}^{m}(-1)^k\binom{m}{k}^2$. Thus, $\binom{2n}{n} = (-1)^n\sum_{k=0}^{2n}(-1)^k\binom{2n}{n}$.

c. From 2b, $\binom{2n}{n} = (-1)^n\sum_{k=0}^{2n}(-1)^k\binom{2n}{k}^2 = (-1)^n\sum_{k=0}^{2n}\left\{\binom{2n-1}{k-1} + \binom{2n-1}{k}\right\}^2 =$

$(-1)^n\sum_{k=0}^{2n}(-1)^k\left\{\binom{2n-1}{k-1}^2 + 2\binom{2n-1}{k-1}\binom{2n-1}{k} + \binom{2n-1}{k}^2\right\}$, since all the "perfect square" terms cancel.

d. We prove $\binom{2n}{n} = \sum_{j=1}^{n}\left(4 - \frac{2}{j}\right)$ for $n \ge 1$ by mathematical induction on n. At $n = 1$, this says $2 = \binom{2}{1} = \left(4 - \frac{2}{1}\right) = 2$, which is clearly true.

Next, assume the identity is true at $n = k$: $\binom{2k}{k} = \sum_{j=1}^{k}\left(4 - \frac{2}{j}\right)$, and consider the case $n = k+1$:

$$\binom{2(k+1)}{k+1} = \frac{(2k+2)!}{(k+1)!(k+1)} = \frac{(2k+2)(2k+1)(2k)!}{(k+1)(k+1)(k!)^2} = \frac{2(2k+1)}{k+1}\binom{2k}{k} = \left(\frac{4k+4}{k+1} - \frac{2}{k+1}\right)\binom{2k}{k}$$

$$= \left(4 - \frac{2}{k+1}\right)\sum_{j=1}^{k}\left(4 - \frac{2}{j}\right) = \sum_{j=1}^{k+1}\left(4 - \frac{2}{j}\right)$$

3. a. $\frac{1}{n+1}\binom{2n}{n} = C_n$, the n^{th} Catalan number, which counts the number of distinct ways to put parentheses in a non-commutative product of $n+1$ factors, so it must be a whole number. For a simpler direct proof, suppose there are n white beads and $n+1$ black beads to be placed on a string. This can be done in $\binom{2n+1}{n}$ ways. If the ends of the string are joined, a necklace results,

and $2n+1$ strings (the cyclic permutations of each other) form the same necklace (since no two of n, $n+1$, and $2n+1$ have a common prime factor), so $\frac{1}{2n+1}\binom{2n+1}{n}$ must be an integer. But $\frac{1}{2n+1}\binom{2n+1}{n} = \frac{1}{2n+1}\frac{(2n+1)!}{n!(n+1)!} = \frac{(2n)!}{(n+1)(n!)^2} = \frac{1}{n+1}\binom{2n}{n}$.

b. Since every prime p with $n < p \le 2n$ divides the numerator but not the denominator of $\binom{2n}{n} = \frac{(2n)(2n-1)\cdots(n+1)}{n(n-1)(n-2)\cdots 1}$, we have $\frac{1}{p}\binom{2n}{n}$ is an integer for each such p.

c. If $R = 2\prod p_j$, where p_j runs through all the primes in $(n,2n]$, then $\frac{1}{R}\binom{2n}{n}$ is an integer by 3.b. and the fact that $\binom{2n}{n}$ is even for all $n > 0$. (It's even because $\binom{2n}{n} = \binom{2n-1}{n-1} + \binom{2n-1}{n} = 2\binom{2n-1}{n}$.)

4. a. Let $H_p(n)$ be the highest power of the prime p that divides $n!$ Clearly $H_p(n) = \left\lfloor \frac{n}{p} \right\rfloor + \left\lfloor \frac{n}{p^2} \right\rfloor + \left\lfloor \frac{n}{p^3} \right\rfloor + \cdots$. (We don't need the fact that, exactly, $H_p(n) = \frac{n - w_p(n)}{p-1}$, where $w_p(n)$ is the sum of the digits of n written in base p notation.) Then the highest power of p that divides $\binom{2n}{n} = \frac{(2n)!}{(n!)^2}$ is $H_p(2n) - 2H_p(n) = \sum_{j=1}^{a}\left(\left\lfloor \frac{2n}{p^j} \right\rfloor\right) - 2\left\lfloor \frac{n}{p_j} \right\rfloor \le a$, where a is the largest exponent such that $p^a \le 2n$, and we used $0 \le \lfloor 2x \rfloor - 2\lfloor x \rfloor \le 1$ for all real $x > 0$.

With $L(n)$ =l.c.m. $\{1,2,3,\ldots,n\}$, it is easily seen that $L(n) = \prod_{p^a \le n} p^a$, where p^a is the highest power of p not exceeding n, from which $\binom{2n}{n}$ divides $\prod_{p^a \le n} p^a = L(2n)$.

b. A careful count of the exact power of each prime p, $1 < p \le 2n$, which divides $\binom{2n}{n}$, yields $\binom{2n}{n} = \prod_{k=0}^{m}\left\{L\left(\frac{2n}{k}\right)\right\}^{(-1)^k}$.

For details, see "An Identity for $\binom{2n}{n}$", by S. W. Golomb, *American Mathematical Monthly*, vol. 99, no. 8, October, 1992, pp. 746-748.

(Note that with $L(x) = L(\lfloor x \rfloor)$ for all positive real x, we have $L\left(\frac{2n}{k}\right) = 1$ for all $k > n$.)

New Books

Raymond Yeung

Information-Spectrum Methods in Information Theory,
by Te Sun Han (translated from Japanese by Hiroki Koga). Springer, 2003, 538 pp., US$69.95, ISBN 3-540-43581-6.
Contents: Source Coding; Random Number Generation; Channel Coding; Hypothesis Testing; Rate-Distortion Theory; Identification Coding and Channel Resolvability; Multi-Terminal Information Theory.

Coded Modulation Systems,
by John B. Anderson and Arne Svensson. Kluwer, 2002, 490 pp., US$125, ISBN 0-306-47279-1.
Contents: 1. Introduction to Coded Modulation. 2. Modulation Theory. 3. Coding and Information Theory. 4. Set Partition Coding. 5. Continuous Phase Modulating Coding. 6. PRS Coded Modulation. 7. Introduction to Fading Channels. 8. Trellis Coding on Fading Channels.

Secure Broadcast Communication in Wired and Wireless Networks,
by Adrian Perrig and J. D. Tygar. Kluwer, 2002, 240 pp., US$115, ISBN 0-7923-7650-1.
Contents: Introduction; Cryptographic Fundamentals; TESLA Broadcast Authentication; BiBa Broadcast Authentication; EMSS, MESS, and HTSS: Signatures for Broadcast; ELK Key Distribution; Sensor Network Security; Related Work; Conclusion.

Fundamentals of Codes, Graphs, and Iterative Decoding,
by Stephen B. Wicker and Saejoon Kim. Kluwer, 2002, 248 pp., US$125, ISBN 1-4020-7264-3.
Contents: 1. Digital Communication. 2. Abstract Algebra. 3. Linear Block Codes. 4. Convolutional and Concatenated Codes. 5. Elements of Graph Theory. 6. Algorithms on Graphs. 7. Turbo Decoding. 8. Low-Density Parity-Check Codes. 9. Low-Density Generator Codes.

Turbo Coding for Satellite and Wireless Communications,
by M. Reza Soleymani, Yingzi Gao, and U. Vilaipornsawai. Kluwer, 2002, 248 pp., US$125, ISBN 1-4020-7197-3.
Contents: 1. Introduction. 2. Turbo Decoding Principles. 3. Non-binary Turbo Codes: DVB/RCS Standard. 4. Spectrally Ecient Non-binary Turbo Codes: Beyond DVB/RCS. 5. Block Turbo Codes. 6. Reed-Muller Codes and Reed-Muller Turbo Codes. 7. Performance of BTCs and their Applications. 8. Implementation issues. 9. Low Density Parity Check Codes.

Probabilistic Logic in a Coherent Setting,
by Giulianella Coletti and Romano Scozzafava. Kluwer, 2002, 296 pp., US$106 (HB), US$31 (PB), ISBN 1-4020-0917-8 (HB), 1-4020-0970-4 (PB).
Contents: 1. Introduction. 2. Events as Propositions. 3. Finitely Additive Probability. 4. Coherent probability. 5. Betting Interpretation of Coherence. 6. Coherent Extensions of Probability Assessments. 7. Random Quantities. 8. Probability Meaning and Assessment: a Reconciliation. 9. To Be or not To Be Compositional? 10. Conditional Events. 11. Coherent Conditional Probability. 12. Zero-Layers. 13. Coherent Extensions of Conditional Probability. 14. Exploiting Zero Probabilities. 15. Lower nd Upper Conditional Probabilities. 16. Inference. 17. Stochastic Independence in a Coherent Setting. 18. A Random Walk in the Midst of Paradigmatic Examples. 19. Fuzzy Sets and Possibility as Coherent Conditional Probabilities. 20. Coherent Conditional Probability and Default Reasoning. 21. A Short Account of Decomposable Measures of Uncertainty.

The Mathematical Theory of Information,
by Jan Jahre. Kluwer, 2002, 520 pp., US$145. ISBN 1-4020-7064-0.
Contents: 1. Introduction. 2. The Law of Diminishing Information. 3. General Properties of Information. 4. Specific Information Measures. 5. Selected Applications. 6. Infodynamics. 7. Statistical Information. 8. Algorithmic Information. 9. Continuous Systems. 10. Continuous Information. 11. Deterministic Dynamics. 12. Control and Communication. 13. Information Physics. 14. The Information Quantum.

Finite Commutative Rings and Their Applications,
by Gilberto Bini and Flaminio Flamini. Kluwer, 2002, 192 pp., US$98. ISBN 1-4020-7039-X.
Contents: 1. Fundamental Notions in Ring Theory. 2. Finite Field Structure. 3. Finite Commutative Rings. Regular Polynomials. 4. Separable Extensions of Finite Fields and Finite Rings. 5. Galois Theory for Local Rings. 6. Galois and Quasi-Galois Rings: Structure and Properties. 7. Basic Notions of Codes Over Finite Fields. 8. Basic Notions on Codes over Galois Rings.

DNA Microarrays and Gene Expression: From Experiments to Data Analysis and Modeling,
by Pierre Baldi and G. Wesley Hatfield. Cambridge, 2002, 228 pp., £35, ISBN 0-521-80022-6.
Contents: A Brief History of Genomics; DNA Array Formats; DNA Array Readout Problems; Gene Expression Profiling Experiments: Problems, Pitfalls and Solutions; Statistical Analysis of Array Data: Inferring Changes; Statistical Analysis of Array Data: Dimensionality Reduction, Clustering, and Regulatory Regions; Survey of Current DNA Array Applications; Systems Biology: Overview of Regulatory, Metabolic and Signaling Networks.

Mathematics of Genome Analysis,
by Jerome K. Percus. Cambridge, 2001, 150 pp., £40 (HB), £15.95 (PB) ISBN 0-521-58517-1 (HB), 0-521-58526-0 (PB).
Contents: Decomposing DNA; Recomposing DNA; Sequence Statistics; Sequence Comparison; Spatial Structure and Dynamics of DNA.

Stochastic Models in Queueing Theory, 2nd Ed.,
by Jyotiprasad Medhi. Academic Press, 2002, 450 pp., £46.95, ISBN 0124874622.
Contents: Stochastic Processes; Queueing Systems: General Concepts; Birth-and-Death Queueing Systems: Exponential Models; Non-Birth-and-Death Queueing Systems: Markovian Models; Network of Queues; Non-Markovian Queueing Systems; Queues with General Arrival Time and Service Time Distributions 333; Miscellaneous Topics.

The Communications Handbook, 2nd Ed.,
edited by Jerry D. Gibson. CRC Press, 2002, 1616 pp., US$169.95, ISBN 0-8493-0967-0.

Communications, Information and Network Security,
edited by Vijay K. Bhargava, H. Vincent Poor, Vahid Tarokh, and Seokho Yoon. Kluwer, 2002, 416 pp., US$110.95, ISBN 1-4020-7251-1.

Data Communication Principles for Fixed and Wireless Networks,
by Aftab Ahmad. Kluwer, 2002, 294 pp., US$125, ISBN 1-4020-7328-3.

Communication Systems: The State of the Art,
edited by Lyman Chapin. Kluwer, 2002, 248 pp., US$150, ISBN 1-4020-7168-X.

System-Level Power Optimization for Wireless Multimedia Communication: Power Aware Computing,
edited by Remesh Karri and David J. Goodman. Kluwer, 2002, 248 pp., US$115, ISBN 1-4020-7204-X.

Wireless OFDM Systems: How to make them work?
edited by Marc Engels. Kluwer, 2002, 232 pp., US$125, ISBN 1-4020-7116-7.

Mobile and Wireless Communications,
edited by Cambyse Guy Omidyar. Kluwer, 2002, 320 pp., US$150, ISBN 1-4020-7250-3.

Advanced Communications and Multimedia Security,
edited by Borka Jerman-Blazic and Tomaz Klobucar. Kluwer, 2002, 320 pp., US$160, ISBN 1-4020-7206-6.

Performance Analysis of Multi-Channel and Multi-Trac on Wireless Communication Networks,
by Wuyi Yue and Yutaka Matsumoto. Kluwer, 2002, 335 pp., US$115, ISBN 1-7923-7677-3.

Phase-Locked Loops for Wireless Communications: Digital, Analog and Optical Implementations, 2nd Ed.,
by Donald R. Stephens. Kluwer, 2002, 440 pp., US$128, ISBN 1-7923-7602-1.

Probability Distributions Involving Gaussian Random Variables: A Handbook for Engineers and Scientists,
by Marvin K. Simon. Kluwer, 2002, 224 pp., US$128, ISBN 1-4020-7058-6.

Compression and Coding Algorithms,
by Alistair Moat and Andrew Turpin. Kluwer, 2002, 288 pp., US$110, ISBN 0-7923-7688-4.

Constellation Shaping, Nonlinear Precoding, and Trellis Coding for Voiceband Telephone Channel
by Steven A. Tretter. Kluwer, 2002, 288 pp., US$125, ISBN 1-4020-7006-3.

Digital Clocks for Synchronization and Communications,
by Masami Kihara and Pekka Eskelinen. Artech House, 2003, 274 pp., £63, ISBN 1-58053-506-2.

Chinese Telecommunications Policy,
by Xu Yan and Douglas C. Pitt. Artech House, 2002, 259 pp., £80, ISBN 1-58053-328-0.

Interference Analysis and Reduction for Wireless Systems,
by Peter Stavroulakis. Artech House, 2003, 356 pp., £76, ISBN 1-58053-316-7.

Workshop Report: 4th Australian Communications Theory Workshop

Alex Grant

February 5-7, 2003
Melbourne, Australia

AusCTW attendees during one of the poster sessions.

The Fourth Australian Communications Theory Workshop (AusCTW) was held February 5-7, 2003 in Melbourne, Australia. The workshop, an activity of the SA/ACT/Vic Sections Information Theory Joint Chapter, concentrates on theoretical aspects of the physical layer, in particular communications and information theory. Specific topics included coded modulation, coding theory and practice, communication systems, channel characteristics and modeling, detection and estimation, DSP for communications, information theory and statistics, iterative decoding algorithms, multiuser detection and space-time coding and processing. The organising committee consisted of Jamie Evans (Melbourne University), Iain Collings (Sydney University), Linda Davis (Lucent Bell Labs, Sydney), Alex Grant (University of South Australia) and Rod Kennedy (Australian National University). The Technical Program was arranged by Thushara Abhayapala (Australian National University) Stephen Hanly (Melbourne University) Stephen Weller (Newcastle University) and Graeme Woodward (Lucent Bell Labs, Sydney). The workshop was generously sponsored by the ARC Special Research Centre for Ultra-Broadband Information Networks (CUBIN), the National Information and Communications Technology Centre of Excellence (NICTA), Lucent Technologies Bell Labs (Sydney), The Australian National University and The University of South Australia.

Since AusCTW is probably not widely known outside of Australia, a brief historical overview may be of interest to international readers. The Workshop began in February 2000 as the Workshop for Early Career Researchers in Communications Theory. The inaugural event was held at Sydney University and was attended by 35 postgraduate students and early career researchers. According to the organizing committee of the first workshop, "*Recently there has been a need in the Australian telecommunications scene for both an outlet for current research results and for bringing together the various research groups focusing on physical layer and related telecommunications research. This workshop will be an opportunity for early career researchers and postgraduate students to gather together in a largely informal environment and share ideas and experiences. The expectation is that the workshop will foster collaborative links, and help cultivate a sense of community amongst young researchers.*"

The Sydney workshop consisted of four research overviews, eleven technical talks and two poster sessions, with a total of fifteen posters. Although the workshop changed name the very next year to the more general Australian Communications Theory Workshop, the goals, spirit and format of the first workshop have been preserved. The 2nd Australian Communications Theory Workshop, 2001 was held in Adelaide, at the University of South Australia (despite the name change, the Sydney workshop counts an number one!). Three research overviews, twelve technical talks and over 35 posters were presented. Numbers grew in the second year to over fifty attendees. Last year, for the 3rd AusCTW, held at the Australian National University in Canberra, we were pleased to produce our first fully refereed proceedings as a lasting workshop record (ISBN 0-9580345-0-8). Over 100 participants attended in 2002 and we were also happy to welcome several international attendees.

This year, the workshop, held over two and a half days on the grounds of Melbourne University, consisted of four 40-minute "Research Overview" talks, twelve 20-minute technical presentations and three posters sessions (with over 20 posters presented in each session). The overview talks are intended to provide a birds-eye view of particular research areas, concentrating on concepts rather than specific technical details. This year, the overviews were presented by Prof. Brian Anderson (Australian National University/NICTA), Prof. Lars Rasmussen (University of South Australia), Prof. Branka Vucetic (Sydney University) and Prof. Rod Tucker (Melbourne University). The technical presentations, given by local and visiting international researchers concentrated in more detail on recent research results. As has been the case since the first workshop in 2000, the poster sessions proved to be the hub of activity and discussion each day. A record of the entire technical program may be found on the Workshop web site, http://www.informationtheory.net/AusCTW2003

At the conclusion of the technical program most attendees followed the tradition of the participating in post-workshop social events, including a visit to Melbourne's new Federation Square, while a few sports fans made a pilgrimage to the famous Melbourne Cricket Ground to see a remarkable session of play in a cricket test match between New South Wales and Victoria.

The workshop proceedings (ISBN 0-9580345-2-4) are available in hardcopy and on CD-ROM, and can be obtained by writing to Rod Kennedy, rod.kennedy@anu.edu.au.

2003 Winter School on Coding and Information Theory

Amos Lapidoth

Monte Verità, Ascona, Switzerland
February 24-27, 2003

The biennial Winter School on Coding and Information Theory celebrated its seventh birthday February 24–27, 2003. Previous winter schools took place in Germany, the Netherlands, Sweden, and Denmark, and this year it made its debut in Switzerland. The 50 participants enjoyed gorgeous weather and beautiful views from Monte Verità, Ascona, on Lake Maggiore.

Participants in the 2003 Winter School on Coding and Information Theory.

The main purpose of the winter school is to provide an opportunity for graduate students from different European universities to meet and learn about each other's ongoing research activities. All participating students are encouraged to present their ongoing research. In total there were 36 presentations given by students from the Universities of Vienna (Austria); Eurecom (France); Essen, Kiel, München, and Ulm (Germany); Budapest (Hungary); Bergen (Norway); Lund (Sweden); and Lausanne and Zürich (Switzerland). In addition there were five invited talks of a tutorial nature: Emre Telatar (EPFL, Lausanne) talked about *Job Scheduling and Multiple Access*, Raymond Knopp (Eurecom, France) presented *Challenges in UWB Signaling for Adhoc Networking*, Hans-Andrea Loeliger (ETHZ, Zurich) introduced *Signal Processing with Factor Graphs*, James L. Massey (Lund, Sweden) talked about *Giving Direction to Information*, and Sergio Verdú (Princeton, New York) presented DUDE: *An Algorithm for Discrete Universal Denoising*.

Beside the rich technical program there was always enough time for social activities, like the Tuesday afternoon excursion up the marvellous Maggia Valley. The participants could enjoy the scenery, visit a small church by the famous architect Mario Botta, and spend the evening in a Grotto — a typical local restaurant.

This year's winter school was chaired by Amos Lapidoth and Hans-Andrea Loeliger from the Signal and Information Processing Laboratory, ETH Zurich. Local arrangements, publications, and the technical program were handled with typical Swiss efficiency by Justin Dauwels, Daniel Hösli, and Stefan M. Moser. The winter school was generously supported by the Information Theory Society of IEEE and the IEEE Switzerland Chapter on Digital Communications.

The proceedings and additional photos can be found on the web at http://www.isi.ee.ethz.ch/winterschool/

Distinguished Lecturer in Seoul

by Jong-Seon No

On 21 April 2003, the Information Theory Chapter of the IEEE Seoul Section hosted a Distinguished Lecture by Vijay K. Bhargava at Seoul National University. The lecture was entitled, "Power-Residues, Binary Matrices with Specified Properties and Error Correcting Codes." In this lecture, using the theory of power residues modulo a prime, Vijay constructed a number of matrices which were symmetric, and/or orthogonal or had low multiplicative order mod 2. For primes of special form, some general results were presented. The resulting matrices could be rather sparse and result in interesting error correcting codes. The lecture was attended by over 40 attendees including students, professors and other local IT professionals. The talk was followed by a lunch during which the photograph was taken.

Members of the Seoul Section of the IEEE with Vijay Bhargava.

DIMACS Workshop on Network Information Theory

Piyush Gupta, Gerhard Kramer and Adriaan J. van Wijngaarden

March 17-19, 2003
Piscataway, NJ

A workshop on Network Information Theory was held from Monday, March 17, to Wednesday, March 19, at the Center for Discrete Mathematics and Theoretical Computer Science (DIMACS) located at Rutgers University, Piscataway, close to the IEEE Headquarters. This event was part of a series of workshops being organized under the auspices of the "DIMACS 2001-2004 Special Focus on Computational Information Theory and Coding", which is a program funded by the National Science Foundation.

The focus of the workshop was on efficient and reliable communication in multi-terminal settings. This field has recently attracted renewed attention due to fast-growing applications such as the Internet, wireless cellular and LAN data services, ad hoc networks and sensor networks. One of the objectives of the workshop was to achieve a better understanding of the underlying information-theoretic problems and their solutions.

The workshop consisted of 27 invited presentations by researchers from all stages of their careers, including past Shannon lecturers and recent Ph.D. graduates. There were 132 registered participants, many of them from the local institutions Rutgers, AT&T Research, Princeton, Bell Labs, Brooklyn Polytechnic, Cornell, but also several from UIUC, MIT, Berkeley, UCLA as well as from Canada, Europe and Israel. A special highlight was that the Information Theory Society's second Shannon Lecturer, David Slepian, paid a visit to listen to Jack Wolf speak on network protocols. The attached photograph shows the legendary Slepian-Wolf team together with Sergio Verdú.

An overview of the program can be found at http://dimacs.rutgers.edu/Workshops/NetworkInformation/

Proceedings of the workshop will be published as part of the American Mathematical Society (AMS) DIMACS Volumes, and will appear during the course of next year.

David Slepian, Sergio Verdú and Jack Wolf at the 2003 DIMACS Workshop.

Stephan ten Brink (Bell Labs) and Michael Gastpar (UC Berkeley) about to enter the lecture hall of the DIMACS Center.

2003 Signal Processing for Wireless Communications (SPWC 2003)

Savoy Place, London,
May 19-20, 2003,

by Mohammad R. Shikh-Bahae

The workshop SPWC2003 (Signal Processing for Wireless Communication) featured invited speakers from Europe, USA, and Japan, and signal processing and Information-theoretic aspects of wireless communication were discussed deeply during the two panel session talks and also in invited speeches. Following is the list of some of the invited speakers:

Prof. F. Adachi, Tohoku University, Japan
Prof. Vahid Tarokh, Harvard University, USA
Prof. Ezio Biglieri, Politecnico di Torino, Italy
Prof. A. Paulraj, Stanford university, USA
Prof. Sergio Verdú, Princeton University, USA
Prof. Ryuji Kohno, Yokohama National University, Japan

The full list, along with the program of the workshop and title of the talks can be found at http://www.SPWC2003.org.

Participants in the 2003 SPWC Workshop.

Call For Papers:

Forty-First Annual Allerton Conference On Communication, Control, and Computing

October 1 – 3, 2003

The Forty-First Annual Allerton Conference on Communication, Control, and Computing will be held from Wednesday, October 1 through Friday, October 3, 2003, at the Allerton House, the conference center of the University of Illinois. Allerton House is located twenty-six miles southwest of the Urbana-Champaign campus of the University, in a wooded area on the Sangamon River. It is part of the fifteen-hundred acre Robert Allerton Park, a complex of natural and man-made beauty designated as a National natural landmark. The Allerton Park has twenty miles of well-maintained trails and a living gallery of formal gardens, studded with sculptures collected from around the world.

Papers presenting original research are solicited in the areas of communication systems, communication and computer networks, detection and estimation theory, information theory, error control coding, source coding and data compression, queueing networks, control systems, robust and nonlinear control, adaptive control, optimization, dynamic games, large scale systems, robotics and automation, manufacturing systems, discrete event systems, intelligent control, multivariable control, computer vision based control, learning theory, neural networks, VLSI architectures for communications and signal processing, and automated highway systems. Also solicited are organized sessions for the Conference; prospective organizers should discuss their plans with the Conference co-chairs before sending a formal proposal.

This year the plenary lecture will be delivered by *Professor Jessy W. Grizzle* of the University of Michigan. It is scheduled for Friday, October 3, and is entitled *"Control and Underactuation in Mechanical Bipedal Locomotion."*

Information for authors: Regular papers, suitable for presentation in twenty minutes, as well as short papers, suitable for presentation in ten minutes, are solicited. The purpose of the short paper category is to encourage authors to present preliminary results of their work. Regular papers will be published in full (subject to a maximum length of ten 8.5" x 11" pages) in the Conference Proceedings, while short papers will be limited to two-page summaries in the Proceedings.

For reviewing purposes regular papers, a title and a five-to-ten page extended abstract, including references and sufficient detail to permit careful reviewing, are required. For short papers, a title and a three-to-five page summary are required. Manuscripts that are submitted as regular papers but cannot be accommodated in that category will be considered in the short paper category, unless the authors indicate otherwise.

Manuscripts must be submitted by **Thursday, July 3, 2003** following the instructions at the Conference website: http://www.comm.csl.uiuc.edu/allerton.

Authors will be notified of acceptance via e-mail by August 8, 2003, at which time they will also be sent detailed instructions for the preparation of their papers for the Proceedings.

A final version of presented papers must be submitted electronically prior to the end of the Conference.

Conference Co-Chairs: R. Srikant and Venu Veeravalli

Email: *allerton@csl.uiuc.edu*
URL: http://www.comm.csl.uiuc.edu/allerton
University of Illinois at Urbana-Champaign

CALL FOR PAPERS

The 2004 IEEE International Symposium on Information Theory will be held in Chicago, Illinois, from Sunday, June 27, through Friday, July 2, 2004. The theme of ISIT 2004, "Exploring New Connections," represents a focus on fostering new connections among people, technical areas and ideas, both within the traditional boundaries of Information Theory, and beyond in related fields. Keynote speakers for ISIT 2004 will be Persi Diaconis, Ueli Maurer, Thomas J. Richardson and Martin Vetterli.

Previously unpublished contributions to the following areas will be solicited:

Coded modulation
Communication complexity
Cryptology and data security
Data networks
Information theory and statistics
Multiuser information theory
Quantum information processing
Signal processing
Coding theory and practice
Communication systems
Data compression
Detection and estimation
Multiuser detection
Pattern recognition and learning
Shannon theory
Source coding

The following tutorials will be offered on Sunday, June 27:

Gilles Brassard: Quantum Information Processing
Michael Fitz, Giuseppe Caire, Hesham El-Gamal: Space-Time Coding
Brendan Frey: Probabilistic Inference Algorithms and Applications
Ueli Maurer: Cryptography

The conference site is the Chicago Downtown Marriott Hotel, located on the "Magnificent Mile" of Michigan Avenue, near the Chicago river and lake front.

Papers will be reviewed on the basis of an extended abstract (not exceeding six pages) of sufficient detail to permit reasonable evaluation. The deadline for submission is **December 1, 2003**, with notification of decisions by March 15, 2004. The deadline will be strictly enforced. In view of the large number of submissions expected, multiple submissions by the same author will receive especially stringent scrutiny. All accepted papers will be allowed twenty minutes for presentation, and one-page abstracts will be printed in the conference proceedings. Authors are strongly encouraged to submit electronic versions of their summaries in the form of Portable Document Format (PDF) files. Detailed information on paper submission, the technical program, special events, tutorial sessions, accommodations, travel arrangements, excursions and applications for travel grants will be posted on the Symposium web site:

`http://www.isit2004.org`

Inquiries on general matters related to the Symposium should be addressed to `chair@isit2004.org`.

Conference Calendar

DATE	CONFERENCE	LOCATION	CONTACT/INFORMATION	DUE DATE
June 29 - July 4, 2003	**2003 IEEE International Symposium on Information Theory (ISIT)**	Pacifico Yokohama, Yokohama, Japan	Prof. Ryuji Kohno Yokohama National University Graduate School of Engineering Division of Physics, Electrical and Computer Engineering 79-5 Tokiwadai, Hodogaya-ku Yokohama, 240-8501 JAPAN +81-45-339-4116 +81-45-338-1157 (fax) isit2003@kohnolab.dnj.ynu.ac.jp http://www.isit2003.org	Nov. 1, 2002
July 6-10, 2003	**2003 IEEE Information Theory Workshop**	New World Renaissance Hotel Hong Kong, China	Victor Keh-wei Wei & Raymond Wai-ho Yeung The Chinese University of Hong Kong {whyeung,kwwei}@ie.cuhk.edu.hk http://itwhk03.cs.ust.hk	Mar. 15, 2003
August 27-29, 2003	**13th IFAC Symposium on System Identification**	Rotterdam, The Netherlands	Prof. Paul Van den Hof Delft University of Technology The Netherlands p.m.j.vandenhof@tnw.tudelft.nl www.sysid2003.nl	Nov. 20, 2002
September 1-5, 2003	**3rd International Symposium on Turbo Codes and Related Topics**	Brest, France	http://www-turbo.enst-bretagne.fr/	March 31, 2003
September 24-25, 2003	**InOWo'03 - 8th International OFDM Workshop**	Hamburg, Germany	Prof. Hermann Rohling Department of Telecommunications TU Hamburg-Harburg, Ei§endorfer Str. 40 D-21073 Hamburg, Germany Tel: +49 (0)40 42878 3228 Fax: +49 (0)40 42878 2881 email:rohling@tu-harburg.de http://ofdm.tu-harburg.de	TBA
October 1-3 2003	**41st Annual Allerton Conference on Communication, Control and Computing**	Allerton House Monticello, Illinois, USA	R. Srikant and V. Veeravalli allerton@csl.uiuc.edu http://www.comm.csl.uiuc.edu/allerton	July 3, 2003
December 1-5, 2003	**GLOBECOM 2003**	San Francisco Marriott San Francisco, CA	Ms. Patricia Dyett IEEE Communications Society 305 E. 47th St., 9th Floor New York, NY 10017 +1 212 705 8999 (Fax) +1 212 705 8943 GLO2003C@comsoc.org	February 15, 2003
January 14-16, 2004	**5th International ITG Conference on Source and Channel Coding**	Fraunhofer Institute for Integrated Circuits, Erlangen, Germany	Prof. Dr.-Ing. J. Huber (Email: scc04@LNT.de) http://www.LNT.de.itg/	July 21, 2003

Conference Calendar

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June 27 - July 2, 2004	**2004 IEEE International Symposium on Information Theory (ISIT)**	Chicago, Illinois, USA	See CFP in this issue http://www.isit2004.org	Dec. 1, 2003
July 19-24, 2004	**2004 Stochastic Networks Conference**	Centre de Recherches Mathematiques Universite de Montreal Montreal, Canada	http://www.stanford.edu/group/stochnetconf/	
September 1, 2004	**2004 ICC**	Paris, France	http://www.icc2004.org	TBA
November 29-December 3	**GLOBECOM 2004**	Dallas, Texas, USA	http://globecom2004.org	July 21, 2003
September 4-9 2005	**2005 IEEE International Symposium on Information Theory (ISIT)**	Adelaide, AUSTRALIA	TBA	

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