

HOW TO WRITE RESEARCH ARTICLES IN COMPUTER SCIENCE AND RELATED ENGINEERING DISCIPLINES

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ABSTRACT

This article advocates a general way of presenting research articles on any topic and in any field related to computer science, information technology, and relevant engineering disciplines. Some examples and implications are given for the case study of wireless sensor networks. The key advice to a successful presentation is to repeat the description of main contribution four times: in the title, abstract, introduction (or chapter 1) and in the text. That is, make readable, appealing, and as complete as possible versions of the work using the order of 10, 100, 1000 and 10.000 words. This corresponds to the decreasing portion of readers for corresponding parts of the article. To the extent possible, each of these parts should address, in this order: the problem statement, existing solutions, the new solution(s), assumptions and limitations, analysis, simulation and comparison with best competing solutions.

1. MOTIVATION FOR WRITING AND READING THIS ARTICLE

The major goal of this paper is to serve as a guideline for the organization of research presentations in written or oral form. The major purpose of the entire effort is to make research presentations as easy to comprehend as absolutely possible. The same structure is valid for thesis work, as well as for conference and journal publications, or technical reports for research sponsors.

While the presented guidelines are general, applicable to any research topic in any field, particular examples and references were made from the field of wireless sensor networks. The primary motivation for writing this article came from the author's participation in *Prosense* project [P]. This article is an expanded

version of a four page manuscript that was posted on www.site.uottawa.ca/~ivan in 1999 under the heading 'Advice for writing theses and papers'.

A decade ago the author had the opportunity to collaborate with Veljko Milutinovic on a research topic in the area of neural networks. The co-authors were first asked to study his presentation guidelines [M1]. The author of this article then adopted this method for writing all subsequent papers, oral presentations, graduate supervision, examinations, and became interested in the topic, which led to this publication.

Another motivation to publish this paper came from the observation that the vast majority of papers in journals, conference proceedings, and the majority of observed oral presentations do not follow the basic structure, as outlined in the abstract of this article. In most cases, research results are obscured by poor presentation. It is not possible to quickly understand, either the essence of the presented contribution, or the most important research details. This is happening despite the presentation advice appearing to be quite natural and effective for easy understanding of contributions made in a given article.

The main *motivation* for writing articles is their *publication*. The acceptance of an article submitted to a journal or conference depends on three factors: *its quality, politics* and *luck*. This article aims at helping to improve the quality of an article by improving its presentation. There is always a factor of pure luck such as selection of reviewers, their bias or fairness, acceptance rate etc. The politics involved are also very important. Many papers are published even in top conferences and journals because of influential authors, despite possible poor presentation or even poor quality. What journal or conference is best for a given article, to optimize (probability of accepting)*(value of journal/conference)? The probability of acceptance depends on factors such as the scope of journal/conference, networking or personal links to editors and committee members (researchers are human

beings, not robots), and the *quality* of paper. Thus the quality is also an input for political decisions. Political decisions are often made by reviewers, based on factors such as *visibility* and *reputation* of authors, competition with other articles etc. Articles of low or high quality bring a corresponding *reputation* to the researcher. The quantity of published articles does not always bring benefits, as even a single low quality article opens the doors for criticism and negative recommendations, even for an upcoming high quality article.

Excellent presentation also brings some risks for the evaluation. A novel idea, well presented, can be claimed to be too simple or even trivial by reviewers, and the judgment is subjective. This author believes in simplicity of any original idea as its ultimate advantage. A number of papers describe new ideas only via programming codes, or complicated diagrams, without presenting clear concise descriptions and/or figures and illustrations on how they work. This style could potentially bring favorable opinions from reviewers that would not admit that they did not understand what has been presented. A well-understood idea also brings the risk of being identified as already existing by reviewers. When it is novel and if well understood, it also becomes easier to identify the drawbacks and criticize it. If a problem statement has a new name, different from the name well-known in the community (meaning that the literature review is not done properly), it becomes difficult to identify proper referees for the article and/or to properly judge its contribution. In summary, there are also reasons not to apply some pieces of advice from this article.

This article places particular attention to four key parts of a research report: the title, abstract, introduction, and to the main body of text. Each of them should be self-contained and complete to the greatest possible extent. Why? Because there are four different types of readers. Among those who will ever see any part of a particular work, perhaps an estimated 80% will see only the title, 15% will read the abstract (and possibly parts of the conclusion in search for information missing in the abstract), 4% will also read the introduction, and the remaining 1% will meaningfully go through the whole paper (some of them may fully read and analyze it, depending on their particular interests and skills, content value, and its *presentation*). Clear and appealing text in one part increases the chances that a reader will go to the next part, and eventually use and cite the work, and thus make a greater impact. The readers could be important persons: thesis examiners, reviewers of conferences and journal submissions. They all have limited time to spend on a particular article and time should be used wisely, to make the greatest possible reading and understanding

progress for a given amount of time. In fact, time spent in itself is a function of clarity and usefulness of text and presentation. If the title is misleading, the abstract is not read. If the abstract does not clearly state the contribution made, and fails to attract the reader, then the reader will not spend time reading the introduction, or the first chapter of a thesis. Sometimes it is beneficial to in fact 'convince' an important reader (examiner, reviewer) that there is no need to study much of the main body of the research report, if the introductory text properly presented the contribution and gave a clear picture of the coming text.

This article does not itself really follow ('recursively') its advice on writing articles. This is because there is no claim of novelty on any part of it. Rather, the contribution is a novel compilation of well-known pieces of advice, some of them cited for the source, some of them probably existing somewhere else. The literature review made here is partial which is contrary to the general methodology applied by this author; with thorough literature reviews being in fact a major component in any research whose goal is to give a novel contribution in an area. The 'related work' section presented here is limited to items identified in literature that are not elaborated elsewhere in this article. The existing pieces of advice on particular topics in sections here are moved to that section, which again is contrary to the general advice for a clear borderline between existing work and contributions.

2. RESEARCH AND PROBLEM SOLVING

Is research a problem solving exercise? Many problems are solved without doing any research. Are there some research activities that do not solve any problems? This author believes that this is not the case. If there is no problem to be solved than the related activity could be a *development*, *implementation*, or another type of work. Consequently, any research begins with a problem statement. Therefore, whenever faced with an article, the first natural question is: what problem has been solved here? Unfortunately, too often the problem is not clearly stated. Sometimes the problem is stated properly, but appears complicated and examples and/or illustrations are missing to facilitate reading.

The author was frequently faced with articles, even grant proposals, that in fact do not have any real problem to be solved. The author was asked once to help a doctoral student from Mexico whose examiners in UK rejected his Ph.D. thesis at the defense, and the advice for recovery remained unclear. The general field of the thesis

was software architecture. After a long session, the student could not define the problem being solved in the thesis (and consequently no help was possible). The poor student was allowed by the supervisor to describe some ‘novel’ software architectures whose evaluation remains fully subjective.

There are other articles in engineering domains where some architectures were described, not necessarily addressing any particular problem. These also occur in the field of wireless sensor networks, especially when dealing with hybrid systems. This does not mean that proposing a new architecture is not a valid research ‘problem’. For instance, a currently ‘hot’ research area is to define new wireless sensor and actuator network architectures, which will be commercial and challenging for further research. However, it is a valid research problem only when the integral parts of doing research are addressed in the article: what problem needs to be addressed by the design of a new architecture, what existing architectures are, what are assumptions and limitations made, how is the new proposal compared with existing ones etc.

This author once wrote a *research* article [S1] on teaching recursion in the first computer science course. When a colleague openly challenged the novelty of this article, the following response was given. Existing textbooks suggested complicated or no proofs that recursive Fibonacci numbers and binomial coefficients algorithms have exponential time complexities (*existing teaching solutions*), which were proven on final exams to not be well understood by students. Article [S1] described an elegant proof in two lines, easily understood by all students, and proven to be effective on the final exam where this technique was applied on a similar algorithm. The proof does not have to be original itself; the main novelty is in applying this proof in the classroom (the proof in fact appears novel).

Along these lines, the application of ‘well known’ mathematical concepts (more precisely, concepts ‘well known’ to some mathematicians) in wireless sensor networks is a research contribution, when these concepts assist in solving a particular problem. One good example is the application of the existing Gabriel graph concept to provide a planar subgraph of unit disk graphs for routing with guaranteed delivery without any memorization at nodes [BMSU].

Technical reports to grant agencies face another challenge. Most people believe they know what the research is, but this is not really the case, and is definitely not the case even with the majority of research grant administrators (particularly in Europe). In virtually *all* grant applications worldwide, *researchers* are asked to

list objectives (which is acceptable), milestones, and the *dates* where each milestone will be achieved. "If we knew what it was we were doing, it would not be called research, would it?" (Albert Einstein). How could Einstein determine in advance when the theory of relativity would be finalized? The current practice mostly contradicts the basic understanding of what research is. If one knows in advance what research results will be achieved at what point in the future, it could be because the problem has already been solved but not yet reported (a safe way to satisfy grant requirements in the final report) or perhaps it is a *development* rather than research.

3. SELECTION OF ‘TITLE’

The selected title of an article should *enable the expert to figure out the essence of the basic idea(s) and the main contribution(s), even without reading the paper* [M1]. Further, the title should *induce the reader to think deeply over the "philosophy" of the contribution* described in the paper [M1].

As an example, consider the title ‘Select and Protest based Beaconless Georouting with Guaranteed Delivery in Wireless Sensor Networks’ [KNRS]. An expert may ‘decode’ this title as follows. First, ‘wireless sensor networks’ is in the title, so the general research field is clearly given, and proper general readership is invited for some attention. ‘Georouting’ means routing with position information (*geographic coordinates*) being available to sensors. Routing in sensor networks refers to sending a message (e.g. field measurement) from a sensor to a sink node. ‘Guaranteed delivery’ would tell many readers already familiar with [BMSU] about the desired property that routing always succeeds, without memorization. It even links it to some other properties like *localized* behavior, where each node knows the position of itself, its neighbors, and destination (sink) only, and not the rest of the network. Otherwise, clearly the shortest path algorithm may be used if globalized algorithm is allowed. ‘Beaconless’ in front of georouting describes a routing algorithm where beacons (or commonly known as ‘hello’ messages) are not used. This means that sensors are not aware of the locations or even existence of their neighboring sensors. When they have a packet to forward, the neighbors are asked to assist by forwarding it. Then some neighbors respond based on their suitability to forward, and the best of them is selected. The main contribution is now clarified, which is beaconless georouting algorithm for wireless sensor networks. But the title starts with ‘Select and Protest based’, which gives the reader a hint about the ‘philosophy’ of the contribution made. The reader can

expect that a forwarding neighbor is somehow selected first, followed by some kinds of ‘protests’ by neighboring sensors that are in good position to judge that the selected neighbor is not the best. The addition of ‘select and protest based’ to the title also may suggest that other solutions to the same problem do exist, and this paper adds a new ‘philosophy’ for solving the same problem. Paper [BMSU], for example, has the shorter title of ‘Routing with guaranteed delivery in ad hoc wireless networks’. It does not give a hint on the philosophy used. On one hand, there is no need for it since this is the first such algorithm. But this is in fact the first *localized* and *memoryless* algorithm for wireless sensor networks, the primary application of it, which do not appear in the title. Perhaps the title should have been ‘Localized memoryless routing with guaranteed delivery in wireless ad hoc and sensor networks’. The ‘localized memoryless’ part fully clarifies the main contribution and assumptions, but does not give the ‘philosophy’ behind the solution used. In this case, ‘localized memoryless’ assumptions, being novel, represent the ‘philosophy’ of the contribution.

The research area of wireless sensor networks is currently very ‘hot’ and there are thousands of papers being published every year. How are papers that are relevant to current research easily detected? The typical approach is to use ‘Google Scholar’ and type keywords. Others do the same, so let your work be easily noticed. If the title is not carefully selected, chances are it will not be observed by many. If problem X is solved using method Y , a title mentioning both X and Y increases chances of being observed by an Internet search using X and/or Y . Papers with appealing and clear titles are likely to receive more attention, be downloaded by more researchers, and gain more citations. Articles with misleading titles may be overlooked by those actually looking for them, as researchers generally do not have much time to interpret various titles. Further, a wrong title may bring wrong referees or examiners for the work, and less appreciation.

4. ABSTRACT: PROTECTING THE CONTRIBUTION

In the author’s opinion, the abstract is the most important part of a research article. Suppose that one has five minutes of time for an oral presentation, or a few hundred words of written space to protect a new idea and contribution and gain deserved recognition. Note that in many cases abstracts are offered freely while the whole paper needs time (and sometimes also financial resources) to download or acquire. Examples are CiteSeer and Springer databases. How would this time or

space be used wisely?

The time/space limitation is in fact almost naturally enforced. Researchers read many abstracts and select few of them for further reading. Most of the others are not found to be important or relevant for the current research, either because it is indeed the case, or because the authors did not make convincing statements to attract attention. The author should make an effort to claim the contribution properly at the most visible place, and not expect readers to do so. Consequently, a good idea may not be noticed by the research community, and those who reinvent it at a later time will get credit instead of the initial inventor [M1] (note: this sentence was applied to the selection of title in [M1], while this author believes that the abstract is even more applicable place for it).

The author agrees with the five part structure of the abstract as described by Milutinovic [M1], as follows:

- a) Problem statement of the research under consideration;
- b) A short list of existing solutions and what their drawbacks are, from the point of view of the above defined problem statement;
- c) Essence of the proposed solution, and why it is expected to be better under the same conditions;
- d) What type of analysis was done to show that the proposed solution is really better than any of the existing ones, from both the performance and the complexity points of view;
- e) What the major numerical highlights of the analysis are.

Milutinovic [M1] recommended one fifth of the sentences to be allocated to each of five items. It is then one sentence for each item for a 50 word abstract, or about ten sentences each for 500 words. More flexibility is recommended here, as illustrated in an example later. Some qualitative (non-numeric) highlights in part e) if feasible are also recommended. The language should be simple and concise.

The abstract should be written for researchers that are familiar with the research area, and can grasp the contribution easily. Some of them could have worked on the same or related problems. A clear abstract is the key to having the work properly credited in other people’s work. One should envision literature reviews of forthcoming papers by other researchers. They could simply ‘cut and paste’ the abstract into their articles, which then serves as an extended ‘patent’ protection. This could be even done semi-automatically, as others do not really need to read or understand the whole article, to cite it properly. If an abstract is without proper content, citations to the article in other papers may not be very informative either. Should they be? It is the author’s

obligation in the first place to properly describe the idea with limited space, without expecting that someone else will do this later on behalf of the authors.

Examiners and reviewers will especially appreciate such an abstract to have a friendly start with the text, and obtain a clear picture in a very short period of time. Misleading abstracts are unfortunately quite common practice in research literature. The limited space is too often simply wasted by writing general sentences about the field and excessive explanations about the problem, that should be part of the introduction or Chapter 1. It is best to first answer the above five ‘questions’, then see whether there is space left to say anything else.

This structure is also suitable for performance evaluation type of articles. In a performance evaluation based article, the problem is to determine the best protocol under various conditions. Existing performance evaluations are existing solutions. What are their drawbacks? Why is this evaluation novel, and what new insights about the protocols are gathered? How does performance evaluation data in this article compare to previous ones?

Survey type of articles however may have a different presentation style. A survey should describe all relevant solutions, classify them according to assumptions made and some properties (that is, present a taxonomy), and draw some conclusions. The contribution of a survey article should still be clarified. It could be the first survey on a given topic or problem, or may present sufficient novel material not covered in existing tutorials, or it could give a taxonomy not seen previously. The survey may also properly describe existing solutions, in a clear and concise manner, compared to existing surveys. A statement of gain the reader will obtain by reading the survey or tutorial article is needed in the abstract.

A recent 300 words abstract from [KSZ] to illustrate how five parts of a survey were covered there is given and discussed here.

‘In a broadcasting task, source node wants to send the same message to all the other nodes in the network’ [KSZ]. This first sentence clearly states what problem has been studied in [KSZ]. However, it is somewhat incomplete, as the ‘network’ and the type of desirable broadcasting are not specific enough. The missing parts are in the paper title though: ‘Parameterless broadcasting in static to highly mobile wireless ad hoc, sensor and actuator networks’. The goal of the article then becomes clear, answering part a).

‘Existing solutions range from connected dominating set (CDS) based for static networks, to blind flooding for moderate mobility, to hyperflooding for highly mobile and frequently partitioned networks. The

only existing protocol for all scenarios is based on some threshold parameters (which may be expensive to gather) to locally select between these three solution approaches.’ This is a brief statement on existing solutions and their drawbacks, answering part b). The best effort was made to achieve clarity with limited space. Some notions and mentioned solutions need to be elaborated later in text, such as connected dominating sets in this example, but an expert on the problem may derive all needed information from this brief text.

‘Here we propose a new protocol, which adjusts itself to any mobility scenario without using any parameter. Unlike existing methods for highly mobile scenarios, in proposed method, two nodes do not transmit every time they discover each other as new neighbors. Each node maintains a list of two hop neighbors by periodically exchanging ‘hello’ messages, and decides whether or not it is in CDS. Upon receipt of the first copy of message intended for broadcasting, it selects a waiting timeout and constructs two lists of neighbors: neighbors that received the same message and neighbors that did not receive it. Nodes not in CDS select longer timeouts than nodes in CDS. These lists are updated upon receipt of further copies of same packet. When timeout expires, node retransmits if the list of neighbors in need of message is nonempty. ‘Hello’ messages received while waiting, or after timeout expiration may revise all lists (and CDS status) and consequently the need to retransmit [KSZ]. These 160 words (more than half of the abstract) are nearly ‘patentable’, and present the main idea of the new solution clearly and concisely. They suffice to protect the solution, and may be easily copied by others in their literature reviews and survey articles. It still does not fully answer part c). This provides a seamless transition of protocol behavior from static to highly mobile scenarios [KSZ]. This is why it is expected to be better than existing solutions. ‘Seamless transition’ is the same as the ‘parameterless’ property from the title. Part c) sometimes should elaborate on assumptions and limitations used in the designed protocol. The main assumption in this solution is the maintenance of a 2-hop neighborhood, achieved by an ideal medium access protocol (this is also a limitation for the protocol).

Our protocol is compared to existing solutions [KSZ]. This states ‘comparison’ as the type of analysis. The sentence is somewhat incomplete. A more complete answer to part d) would be: ‘Our protocol is compared to existing solutions by simulation’. The author of this article observed that comparison with competing solutions is usually not part of the advised simulation or analysis, and consequently not part of other advice for presenting research results cited here in the reference list. In most cases, either there is no comparison, or

comparison is done with a solution that uses different metrics or assumptions, and is therefore not competing. More discussion on this point can be found in [S2]. The comparison with existing solutions does not need to involve simulation, if there is a clear argument showing why the new method is winning, or a convincing analytical approach was used to make an alternative theoretical claim. Sometimes both analytical approach and simulation are used for a more detailed comparison. In such cases the part of the abstract corresponding to d) would be larger. The analytical approach may also be applied to study the performance of only new protocol, with or without comparing it with existing solutions. Obviously, if a solution is the first one under stated assumptions (e.g. when the problem itself is novel) then there is no need for any comparison, as there is nothing appropriate to be evaluated against. In such cases, part d) is answered by simply stating that the presented solution is the first one for the problem stated (a very brief answer to part d)).

‘It was shown to be superior to all of them in number of retransmissions and reliability’ [KSZ]. This answer to part e) could be more elaborative, and with some numerical details. However, in this case, numerical data came after the qualitative difference in two protocols, seamless transition, also in favor of the new one, thus there does not seem to be a tradeoff to elaborate about. In other cases, numerical data may be more important to show in the abstract itself. However, statements should be carefully made. Statements in most abstracts seen in literature are very simplistic, like ‘our new protocol provides 60% longer network lifetime compared to an existing solution’. This looks like a fixed ratio regardless of parameter values used in the protocol. When the section on experimental data is consulted, the comparison varies based on the specific parameter values used. The abstract should then be more specific about parameter values in quoted comparison, or more generic, covering wider ranges of parameters. For example, the statement containing numerical data could state: ‘the accuracy increases to over 70% for average number of neighbors ranging from 3 to 15.’ This author prefers qualitative comparisons with generic statements in the abstract, such as, for example: ‘The new schemes are conceptually simpler than existing ones, and have similar or somewhat better performance in our experiments.’ It refers to the complexity of the solution and relative performance. The complexity could refer to the time complexity of the new solution, and a faster algorithm could be often more complicated.

In the example given, parts d) and e) appear brief. This is because, given the limited space, it is more important to protect the main idea then to elaborate on

the experimental data or theoretical analysis of these ideas. These parts normally do not have pending contribution issues.

5. CONTENT OF INTRODUCTION OR CHAPTER 1

In brief, the introduction of a paper intended to be published in a journal or conference, or Chapter 1 of a master or doctoral thesis, should present the same content (summary of the article), in the same order, as the abstract, with more space provided. Normally it is about ten times longer as a rough approximation. There is also space to address some possibly additional items, such as motivation.

While an introduction is normally a single section, Chapter 1 should have separate headings to address the structure and natural flow in the explanation. The abstract may be sufficient for an expert in the field (researchers who have worked on the same problem, e.g. broadcasting in the above example). The Introduction or Chapter 1 should suffice to comprehend the essence of contribution for people generally working in the area. In the presented example, researchers with articles dealing with any network layer issues in wireless sensor networks should be able to correctly understand what the important aspects of the contribution are, and how good the contribution is.

In this author’s view, the introduction or Chapter 1 should present sufficient information, and be sufficiently self-contained, so that important readers and evaluators do not need to read the rest of text, being assured in the contribution made, and validity of the text to follow. If they are pressured with shortage of time and the need to make a decision on the value of the article, or a citation and reference to it in their own work, let this part give answers to all important possible questions, and earn appreciation. Readers and especially followers of the specific research directions will appreciate such a style and will prefer mentioning such work rather than the work of someone else who remained unclear in the introduction and the article was never read due to the lack of time or loss of confidence.

Here are recommended sections, or subsections, or parts of an introduction.

- i) General overview of the field (basic facts needed to tune the reader to the thesis or paper);
- ii) Problem statement (precise definition and importance); very technical definitions and statements should be avoided (and presented in later text) and instead, good intuition for the

- involved definitions or facts should be presented and even illustrated if desirable.
- iii) Existing solutions and their criticism (limited normally to only those directly relevant to the contribution of the thesis); a motivation for doing research on the topic should be stated;
- iv) Contributions (proposed solutions; why they are expected to be better; essence of the idea(s) used in proposed solutions);
- v) Conditions, assumptions and limitations of the research done;
- vi) Analysis (theoretical, experimental, simulations, implementations,...) done in the thesis; under what conditions and scenarios is the new solution the best one?
- vii) In case of thesis work, it is recommended to add specific statements about the contribution of the thesis author to the thesis work, and the contribution of the thesis to the research field. This is normally done by listing all existing and intended journal and conference publications out of the thesis, which include their authors and titles, and references to proper sections in the thesis.
- viii) The structure and content of the rest of the document is normally outlined at the end of an introduction or Chapter 1 in a single paragraph.

Sections iii), iv), vi), should normally present the highlights, with pointers to later sections and chapters that provide details. The introduction should attempt therefore to present a full version of the article in a concise, readable and intuitively clear form.

6. LITERATURE REVIEW: THE NEXT SECTION OR CHAPTER

Chapter or section 2 should give a full literature review. Many articles present it at the end of the paper, leaving the reader to wonder about the actual contribution until the very end of the text. The literature review (or related work section) should collect all known results relevant to the problem stated, whether or not they are used in the proposed contributions. No additional literature review shall be added in later chapters. In later chapters, the text could only refer to well known results (e.g. those covered in the undergraduate computer science program such as Dijkstra's shortest path algorithm, sorting algorithms etc.) which can be reasonably assumed to be public knowledge for the particular field. In these cases, they should not be described (that is, if there is a need to describe how a 'well known' shortest path algorithm works, then this should be done in the literature review section).

It is important to underline the need for a clear cut, *clear separation line*, between existing work and new ideas being presented in the paper. There are in fact three such separation lines: one in each of the abstract, introduction (or Chapter 1) and the most important one between the literature review section and the rest of text. That line should be very sharp.

In some cases, the paper may present minor variations, with major consequences, of an existing solution. In this case, the contribution may look large in the essence, but short in text. This author still advocates to separate these two, even if it means a single paragraph of text in describing novel ideas.

For example, [SD] contains five pages of literature review on existing power aware greedy localized algorithms [SL2] which does not guarantee delivery, and the existing hop count based on georouting with guaranteed delivery [BMSU]. It is then followed by a single page describing the new contribution, combining them into a single power aware georouting with guaranteed delivery protocol.

This approach however may not receive positive feedback from reviewers (or sometimes even co-authors) that do not share this philosophy. Separation lines are then needed inside the text itself as a compromise. The main problem with placing separation lines inside the text, rather than by placing content in different sections, is that the separation between existing and new ideas easily remains unclear if the presentation is not very careful. Of course, the assumption here is that the primary intention was to be honest with the contribution made in the article.

One of the major pieces of advice this author could give is to do a really *thorough literature review* on the suggested topic. In most observed cases, however, this does not occur. This is also not really advocated by most supervisors. It is also not emphasized in other papers seen on how to write research articles. This author has even seen PhD theses without any literature reviews on the topic. Usually it is required to do a thorough evaluation for the proposed idea, with or without comparing it with something else that exists. Rarely, the requirement is to compare with *competing solutions*, the best existing solutions under particular assumptions, metrics, and models. Finding them requires a thorough literature review.

While on one hand doing a thorough literature review could prove to be 'dangerous' for the new idea in mind, it is expected to be very rewarding in the long term, as it opens the views to different models, assumptions, different problem statements, and offers material for new contributions with much greater compensation for potentially lost contribution. In fact,

ideas are normally credited to original authors anyway, not to those that duplicate it (sometimes it takes time for the community to recognize the duplication e.g. [BMSU] was cited over 500 times, while its later duplication was cited over 2000 times). One of the identified problems is that the existing practice is to merely cite a paper on the subject of study, without thoroughly studying it, or describing it properly, which opens the door for an even more dangerous duplication, one that eliminates the ‘excuse’ of possible ‘independent work’ (the same example with the duplication of [BMSU] is applicable, details are on www.site.uottawa.ca/~ivan).

It is very easy for a reviewer or even examiner to save his time by observing a missing important reference, and claiming that that the particular reference may solve the same problem in a better way. That may or may not be true, but some decisions are not recoverable (e.g. in the case of conference submissions).

For every discussed reference, it is very important to relate them to the stated problem and contribution in one of several ways: it does not exactly solve the same problem, it solves the same problem but makes different assumptions about the system, it has some additional limitations, or it makes the same assumptions but does not work well under certain important conditions and scenarios that are the primary target of the new solution. A clear statement for each identified solution in this respect is recommended. The space allocated to describing existing solutions should also be ‘proportional’ to its closeness to the new idea and assumptions. Some solutions do not need to be described at all, and a simple convincing statement of why they do not solve the problem at hand may suffice. Other solutions may need a brief description of the general philosophy of the solution before being able to make a similar statement. Otherwise the solution is a candidate to be a competing one, and requires more attention and space. Such existing solutions need clear, concise descriptions of how they work, so that readers can understand a comparison. They are targets for ‘defeat’ by analytical and/or experimental comparisons. There might be a clear reason why a particular competing solution is inferior to the newly proposed one.

For example, globalized algorithms in wireless sensor networks have huge communication overhead to gather the information. Although theoretically applicable for solving a problem (e.g. shortest path for georouting), the argument is clear and they may be simulated only as potential benchmarks, not as competing solutions, or not simulated at all. Inability to ‘defeat’ a particular solution certainly leaves a negative impression on readers.

Some of the practices used in published papers on wireless sensor networks are reported in [S2] which

studies aspects related to simulation. In particular, the ‘I am the best’ approach often used is elaborated there. It also discusses comparison with existing solutions to *the same* problem (with same assumptions and metrics), need for thorough literature review, simplicity, proof of concept, and independent variable issues.

In summary, the literature review should be a critical one. It should discuss advantages and drawbacks of known solutions that are relevant to the problem studied, and also discuss the relevance of each reviewed item to the topic studied and newly proposed solutions.

7. THE REMAINING CHAPTERS OR SECTIONS

The remaining chapters should present new contributions (including conditions, assumptions, and limitations, where appropriate) and their analysis. That is, the very same items listed above should be presented in full, preferably in the same order. Assumptions refer to the simplifications made in the model used, so that the solution can be easily understood, while preserving most properties of a realistic model and enabling easy theoretical and/or experimental tractability. Analysis could be analytical, simulational or implementational. Analytical analysis could provide, for example, the proof of validity of the major ideas of the paper (e.g. why the routing in [BMSU] guarantees delivery). It could lead to a rough estimation of the performance (e.g. message complexity for communication among sensors or average/worst time complexity for computation in sensor processors), calculation of parameter values for simulation, and other relevant properties and findings. Currently, sensor prices are reasonable, and many groups have them available. Some protocols, under some assumptions, could be implemented (or emulated) on actual sensor test beds.

One should always keep in mind that a figure may be worth a thousands words. Important new concepts, and new ideas, should be illustrated by examples and figures as appropriate, to help the reader in understanding them, and to demonstrate one’s own understanding of these concepts. This author found most mistakes in student’s understandings by simply asking them to give different types of examples. The same is with readers. Examples should not be trivial, but meaningful and helpful.

Figures with examples, and diagrams with performance evaluation, should not be overly repetitive. A new example is welcome if it offers something essentially different and insightful compared to previous ones. Similarly, additional performance diagrams are welcome only if they offer new performance data,

substantially different from data in previous diagrams, for the selected set of parameter values. Repetitive diagrams offering similar value for the analysis should be omitted or moved to an appendix of a thesis. The overall contribution is not evaluated by the overall length of a thesis or paper, but by its technical content. In other words, the additional size in page length should be justified by the additional contribution, explanation and insight made.

As advised by Milutinovic [M1], captions deserve special attention, which is neglected in a typical written presentation. Reading only the figure captions of the paper should almost substitute the first rough reading of the entire paper. Pseudo-code description (if used) should include the mnemonic name for the algorithm, its input and output (such pseudocodes should be preceded in text with clear concise descriptions of same algorithm). In case of simulation diagrams, parameter values and protocol names must be clearly visible and/or listed in the caption. Captions should include title, description of one or more phenomena that deserve attention, explanation (essential reason for observed behavior) and possibly the implication for the protocol/system design.

It is a very difficult task to find a new solution that is best in all circumstances. The primary task in the simulation part of an article is to identify assumptions, metrics, models and parameter values for which the new solution is better than existing ones. The authors should search for scenarios in which their solution is the best. More details on simulation can be seen in [S2]. One should not be overly optimistic about new ideas and make unfounded claims. A smaller but justified claim is better than a large unfounded claim. Bigger claims open bigger doors for attacks by referees and examiners. Referees may easily turn down the complete idea because of an unsupported large claim, but can also easily accept even a minor contribution if it is well documented and proven.

One of the key pieces of advice is to include all the possible criticisms of your own idea and contribution directly in the article. It is much better that authors criticize their own work and demonstrate good judgment than to leave such 'pleasure' to the examiners and referees. Authors should show that they are in full control of the problem, solutions, and their performance.

8. ON CONCLUSIONS AND REFERENCES

Some people read only the abstract and the conclusion. Thus important things missing in the abstract should be placed in the conclusion section. It could state what has been achieved by the current research, and could discuss and reiterate major advantages and drawbacks of the new

solution. The most important part of the conclusion section is to list future work that can be done using the results of the current article. This may offer readers with some open problems to study, and such feasible problems could lead to later citations of the article. Sometimes the space can be used to in fact briefly outline some ideas that the author intends to develop further. The ownership of some other possible solutions, not fully explored, to the same or a relevant problem, or subject of your forthcoming different article, can be protected by outlining them briefly in the conclusion section, possibly even with reference to an upcoming article.

One recommendation is to follow a +-+ pattern in the introduction and the main text. That is, to start with positive enthusiastic comments about new work and the contribution, then become realistic and list all the drawbacks and limitations, but then finish on a positive note, with a clear statement about the value of the new contribution. It is important that the reader finishes reading the article with a positive impression. (S)he might be writing a follow up report afterwards.

This author routinely uses referencing in the style shown here, e.g. [BMSU] from the first letters of the family names of the co-authors, instead of the normally requested styles such as [1], 2. etc. This allows for dynamic inclusion and exclusion of references (otherwise there exists a natural reluctance due to the additional work involved in correcting the numbering for the rest of the references), and their easy portability to subsequent articles. It also provides easy 'decoding' to readers of the article, much better than constantly turning to the last page to see who the actual contributor is for the given citation. To reduce such needs, it is also recommended to add the family names to references inside the text the first time they are cited. The transformation of the citation style to a possibly different form, in the text and in the reference list, is done only for the very final document, and only if enforced.

9. OVERALL FLOW AND APPEARANCE

It is important to check if the article has an overall flow, a smooth transition from topic to topic. Within each of the abstract, introduction, or main text, repetitions should be avoided. One statement and its description should be given in a single, most suitable place in that part of the article.

Finally, after the scientific presentation is deemed acceptable, it is time to pay more attention to the language used and the overall appearance. It is very important to use proper English grammar and sentence structure. Help may be required if the English language used is not up to the required standard. Misprints must be

corrected. The best approach is to read the article carefully one more time, after some delay of time, and check for possible errors including misprints (it also helps in improving the overall technical content and presentation). One always expects very professional referees and examiners. Their opinion is partially subjective, compared to, say, an evaluation expected from a knowledgeable robot. A good approach in extracting a positive impression for the subjective part of the overall evaluation is by showing the overall care taken in writing the article.

10. RELATED WORK ON PRESENTING RESEARCH ARTICLES

There is plenty of advice for writing research articles that can be found on the Internet. However, most of it deals primarily with language, grammar and formatting issues, and does not go deeply into discussing how to properly and effectively present the essence of the contribution made in a given article.

Milutinovic [M1, M2] wrote two short but extremely useful articles on the best methods for the presentation of research articles. His instructions for preparing transparencies [M2] are complete and we found no need to elaborate on them further or to prepare our own article on this (students are simply asked to use that article). As a particular novelty in [M1, M2], Milutinovic convinces the researchers to use his semantics based layout strategy for transparencies. This article will not elaborate further on oral presentations, and will concentrate on written ones (but the majority of advice is transferable).

Alba [A] presented some brief comments and advice addressing the following problems that students and new researchers face: structure the document, formatting guides, content, readability, electronic edition and diffusion. The suggested structure of the document is: Introduction, Problems (this part includes literature review), Resolution methods, Experiments, Results, Conclusions, and References. Resolution methods should stress the novelty of the method and approach, a specific non-ambiguous explanation of the method (e.g. pseudocodes), mathematical or formal issues of proposed techniques, parameters and most important decisions made to select these methods or techniques, plans to solve the problems with proposed 'wonderful' methods, and expected results after having done so. The experiments section should present the goals and sets of experiments, parameters, algorithms and problem instances intended for use (preferably in table form),

measures, statistical analysis, and criteria to judge the value of the results, steps to follow to get the results with justification. It is recommended to the reader to read [A] for the remaining advice from the list above.

Woodford [W] lists the overall steps in writing a journal article, dissertation or grant proposal, in a brief note, while the full text is available in his book. It begins from asking whether the time is right for writing, to analyzing and possibly answering the examiner's remarks.

Recommendations for writing articles also depend on the research field. This article is written for engineers and computer scientists. Sherrill [S] briefly described recommendations for writing articles in the chemistry discipline. The parts of a paper are: Abstract, Introduction, Methods (or Theoretical Methods), Results and Discussion, and Conclusions. In the Methods section, one 'should give sufficient detail that anyone else who is properly trained in a particular subfield should be able to reproduce results' [S]. For routine applications of standard methods, this part should be as clear as possible, usually 2-4 paragraphs. For papers developing new theoretical approaches, this is usually the bulk of the paper. Similar structure for papers can be found in other fields, e.g. psychology.

The author of this text has a background in mathematics. The structure of a research paper is less rigorous in that field. Normally papers are collections of theorems and proofs, and every known proof from other sources is cited in the text where needed. Cheney [C] compiled an interesting article about writing math reports. They appear applicable because math is ordinarily used in computing and engineering articles. Here are a few of pieces of advice that are found to be quite relevant. Their application is not restricted to the math content of an engineering or computer science report, but can be generalized to other content there, such as the description of algorithms, protocols and systems. 'Mathematics is preeminent in its striving for absolute precision in its formal written text. Precision in writing is not easily attained, but one always begins by using the correct word at the proper place and by carefully constructing each sentence. We also advise against the use of slang, colloquialisms, and other non-standard linguistic devices' [C].

'Use English descriptions and English text in preference to mathematical symbolism wherever possible.' [C]. For example, to define the unit disk graph model that elegantly simplifies wireless sensor networks, there are two basic options. Using math formalism, one can define a unit disk graph G over set of sensors S as follows: $G=(S, V)$, $V=\{(u, v), |uv| \leq R\}$. Despite being a

mathematician, this author would always prefer instead to see an alternative definition as follows. In unit disk graph model, two sensors can communicate with each other if and only if the distance between them is at most R , where R is the common transmission radius. ‘It makes for smoother reading...mathematical symbolism is by its nature INTIMIDATING, even to mathematicians. There is nothing so daunting as having to read a page of formulas! Keep the formulas to a minimum and avoid symbols if ordinary language will do as well. There may be cases where, for good reason, one wishes to violate this rule. But it should be a good reason!’ [C].

Another good reason to avoid math formalism is the impact of possible misprints. A single misprint anywhere in a fully mathematical formula and the expression can have disastrous consequence for the interpretation and understanding, not only of that particular formula but the rest of the text. In some cases, the reader is even unable to continue reading the article. On the other hand, a single misprint in an English sentence, even an awkward English sentence, allows the reader to automatically correct and continue reading. In some cases, the best approach is to give a math expression followed by its ‘decoding’ with analogous statements in English. Sometimes it is simply not easy to avoid math symbolism without losing precision. After helping the reader with an additional English sentence, the reader may be ready to accept the symbolism and apply it to the rest of the text.

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