Link Budget Improvement of Cooperative Diversity with WCDMA Method Implementation

Giorgi Tabuashvili

***Abstract*—Cooperative transmission has been of growing interest recently where users take advantage of each other's resources for better overall performance. User cooperation provides uplink transmit diversity even when mobile units cannot accommodate multiple antennas due to size constraints. Recently, a versatile user cooperation method called coded cooperation diversity was introduced by many researchers, in which a variety of channel coding methods are used to implement cooperation. Different radio access methods could be used for this implementation. In this work, we calculate the link budget and cell radios for cooperative communication with WCDMA access method and mini TDMA scenario between mobiles. Calculation is done for urban, medium and residential areas based on computer simulation. Two propagation models: Motorola Xlos and Ericsson indoor propagation models are used for this. The link budget calculation and simulation results show the advantage of cooperative communication, which prolongs cell radius and improves receiver sensitivity.**

***Index Terms*—Cooperative communication, link budget, propagation model, WCDMA access method.**

I. Introduction

In the 21st century wireless networks become dominant; with different mobile devices, such as mobile phone, laptop, iPad etc. being connected to other devices by some means of wireless networks. Transmission over wireless channel suffers from random fluctuation in signal level known as fading. One of the powerful techniques to mitigate fading is diversity. Using diversity technique the transmitter sends more than one copy of the transmitted message, so the receiver can use these multiple copies to detect the sent message correctly. Since it might be difficult (or impossible) to provide more than one antenna in wireless devices due to small terminal size and other factors, a new way of realizing diversity has been introduced, which is known as cooperative diversity. Cooperative communication allows single wireless devices to share their antennas during transmission and to form a spatial diversity environment and virtual multiple input multiple output (MIMO) system. Cooperative diversity can increase the reliability of wireless networks, increase data speed or prolong cell radius by lessening the effect of fading. The three commonly used cooperation strategies are amplify-and-forward (AF) [1], decode-and-forward (DF) [2], [3] and coded cooperation (CC) [4], [5], [6]. The first one is in fact the simplest cooperative method, in which each user receives a noisy version of the signal transmitted by its partner and then amplifies and retransmits this noisy signal. In the "Detect or decode and forward" method each user attempts to detect or decode the other user's bits and then transmits an estimate or re-encoded version of the detected bits. The third one is a scheme in which different portions of each user's code word are transmitted via independent fading paths. This scheme is called the coded cooperation method. In comparing the three cooperative transmission schemes in [7], we see that both amplify-and-forward and hybrid decode-and-forward are not very effective at low signal-to-noise ratio (SNR). This is due to the fact that their signaling is equivalent to repetition coding, which is relatively inefficient at low SNR. Coded cooperation, however, has graceful degradation and performs better than or as well as a comparative non-cooperative system at all SNRs. In addition, coded cooperation generally performs better than other cooperative methods for moderate to high SNR [7].

We aimed to estimate link budget for inter-user channel and between mobile and base station (BS) for both non-cooperative and cooperative cases. We used wideband code division multiple access (WCDMA) technology with mini time division multiple access (TDMA) scenario. The reason for this choice along with explanations is given in the next section. The kind of output of this work is more visible and provides more confidence for the idea of future practical implementation of cooperative communication systems. It is easy to compare both cases and see the waited result in such manner as it is usually seen by vendors, operators or wide number of radio-frequency (RF) planners. In order to achieve required bit error ratio (BER) or block error ratio (BLER) for deferent services, based on the coded cooperation performance given in T. E. Hunter's dissertation, we adjusted, for our purpose, the energy per bit to noise power spectral density ratio (E_b/N_o) since it does not exist yet for cooperative communication in any international communication organization or project as a recommended one.

II. Input Data and System Model

Cooperative communication, assumes that the BS can separately receive the original and relayed transmissions. The most straightforward method is separation in time, that is, the user's data and relayed data are transmitted in non-overlapping time intervals. Orthogonality also could be achieved via spreading codes. In principle, it is also possible to achieve separation in frequency. Separation of signals is closely related to the issue of hardware requirements on the mobiles. In cellular systems, even TDMA ones, the uplink and downlink transmissions are performed on separate frequency bands. Ordinary mobiles receive only in the downlink band, but cooperative mobiles need to also receive in the uplink band, thus requiring additional input filters and frequency conversion. Another technological issue is transmit and receive requirements on the mobiles. In TDMA systems this is generally not a problem, since the uplink transmissions by definition are non-overlapping in time.

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Giorgi Tabuashvili is with the Faculty of Power Engineering and Telecommunication, Georgian Technical University, Tbilisi, Georgia.

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However, in other multiple access systems, such as CDMA, the mobiles may be required to transmit and receive at the same time. Transmit signals can be up to 120-140 dB above the level of receive signals, which is beyond the isolation achievable by existing directional couplers. Several preliminary solutions to this problem could be found. In our opinion, from a practical point of view the most easily realizable is that, cooperating users may agree to "timeshare" their uplink (UL) transmission, so between the two they will create a mini-TDMA scenario where each transmits for 50 percent of the time at twice the power. So for cooperative cellular modeling we chose the WCDMA radio access method with mini-TDMA scenario between partners. It should be noted, that the orthogonal frequency-division multiple access (OFDMA) method may be applied for this purpose as well. Since many operators use 2100 band for 3/3.5G services, middle downlink (DL) frequency 2140 MHz and middle UL frequency 1950 MHz are also used for modeling.

We calculated link budgets for conventional case, inter-user channel and cooperative case. During the calculation we assumed worst case, which implies in-building signal penetration. We needed to convert the calculated maximum path loss between partners into partnership range for in-building environment. The propagation loss inside building depends on many factors like wall loss, floor loss, building type etc. Some empirical models of propagation within buildings exist. We chose the Ericsson indoor propagation model for which a knowledge of building characteristics was not required and well approximates signal attenuation in Pico-cell environment. In order to predict signal strength or path loss between mobile and BS, based on limitations of different propagation models we chose Motorola Xlos one. Xlos adjusts for built-up or natural environments on top of the terrain by adding a height to the existing terrain for each category of land use/cover data (urban, suburban, rural, foliage, water etc.). The final estimated total attenuation for each mobile position is a varying mix of both reflection and diffraction loss terms. But before these models are applied we calculate maximum and allowed path losses for all cases.

A. *Conventional Link Budget*

First, let us define assumptions and parameters for input data for conventional link budget and propagation models. We did not aim to calculate or derive all involved parameters in this article, since a conventional methodology of UMTS network planning and link budget calculation is well known and described by other authors. In some cases, instead we used the most popular practical values. Some assumptions that have been used for a receiver and transmitter are shown in Table I.

TABLE I: ASSUMPTIONS FOR A MOBILE AND BS

	Mobile	BS	Units
Antenna gain	0	18	dBi
Body loss	4	0	dB
Cable + connection loss	0	2	dB
Noise figure	6	2	dB
Maximum total output power (12.2kbps/384kbps) for Conventional case	0.125/0.25	40	W
Height	1.5	30	m

The target load level of the network should be based on as accurate predictions, as possible, of service & traffic mix distribution and growth. DL load usually bigger than UL load (traffic asymmetry, bigger Eb/No requirements, overhead due to soft handover ...). It is not so hard to manage DL load when close to maximum loading is utilized, due to effective averaging of transmitted powers. During the planning we used the most frequently used values which are 0.75 and 0.5 for DL and UL respectively.

Maximum transmit power for mobile (power classes that are used most frequently in networks) is 21 dBm for voice 12.2 kbps and 24 dBm for 384 kbps data respectively (data terminal may have higher TX power).

Noise figure (NF) is specified in 3GPP, but vendor's product performs better than the 3GPP requirement. We assume maximum total output power for BS is 40 W (46 dBm). The transmitter power on TCH for BS is:

$$P_{tx.tch} = \frac{(1-\eta_{OH}) * Total\ TX\ power}{\eta_{DL} * N_{pole}}$$

1) η_{OH}: the percentage of the overhead channel power.
2) N_{pole}: the upper bound of the capacity, referred to as the pole capacity.

For the control overhead we can refer to table II with example of recommended common channel powers. Below we have the next types of common channels: common pilot channel (CPICH), primary synchronization channel (P-SCH), secondary synchronization channel (S-SCH), Primary common control physical channel (P-CCPCH), Secondary common control physical channel (S-CCPCH), Paging indicator channel (PICH), Acquisition indication channel (AICH). We assign 5.6 W for common channels and control overhead becomes 0.14.

3) η_{DL} : DL load, assumed 0.75.

A closed-form equation can be applied to the downlink pole capacity:

$$N_{pole} = \frac{(1-\eta_{OH}) * {}^{W}\!/_{R_b}}{{}^{E_b}\!/_{N_o} * \nu * \left(1-\alpha + {}^{I_{oc}}\!/_{\hat{I}_{or}}\right)}$$

1) W: the spreading bandwidth of the system, fixed by the standard at 3.84 MHz.
2) Rb: the radio access bearer user bit rate for the selected application.
3) Ioc/Îor: the interference factor. Depends on the antenna configuration and network topology, it may greatly vary due to load variations in adjacent cells. The average interference factor in macro-cell

TABLE III: UMTS LINK BUDGET FOR CONVENTIONAL CASE

		Downlink (target load=0.75)		Uplink (target load=0.5)		
	Path components	12.2 kbps speech	PS 384 kbps	12.2 kbps speech	PS 384 kbps	Units
		BS		Mobile		
Transmitter characteristics	Total transmitter power	40	40	0.125	0.25	W
	Transmitter power on TCH	33	43.6	21	24	dBm
	TX antenna gain	18	18	0	0	dBi
	TX cable+connector loss	2	2	0	0	dB
	TX Body loss	0	0	4	0	dB
	Transmitter EIRP	49	59.6	17	24	dBm
		Mobile		BS		
Receiver characteristics and margins	RX antenna gain	0	0	18	18	dBi
	RX cable+connector loss	0	0	2	2	dB
	RX Body loss	4	0	0	0	dB
	Thermal noise density	-174	-174	-174	-174	dBm/Hz
	Receiver noise figure	6	6	2	2	dB
	Receiver noise density	-168	-168	-172	-172	dBm/Hz
	Receiver noise power	-102.2	-102.2	-106.2	-106.2	dBm
	Interference Margin (=-10 log (1-Target load))	6	6	3	3	dB
	Spreading gain	25	10	25	10	dB
	Required Eb/No	6.7	5.2	4.5	2	dB
	Receiver sensitivity	-114.5	-101.0	-123.7	-111.2	dBm
	Diversity gain (Eb/No includes div. gain)	0	0	0	0	dB
	Fast fading margin (power control headroom)	0	0	4	4	dB
	Soft Handover gain, multicell	1	1	2	2	dB
	Max. path loss	**160.5**	**161.6**	**154.7**	**149.2**	dB
Urban area	Log-normal fade margin	10	10	10	10	dB
	Indoor loss	16	16	16	16	dB
	Allowed propagation loss	**134.5**	**135.6**	**128.7**	**123.2**	dB
Medium area	Log-normal fade margin	11.75	11.75	11.75	11.75	dB
	Indoor loss	11	11	11	11	dB
	Allowed propagation loss	**137.7**	**138.8**	**131.9**	**126.4**	dB
Residential area	Log-normal fade margin	11.75	11.75	11.75	11.75	dB
	Indoor loss	8	8	8	8	dB
	Allowed propagation loss	**140.7**	**141.8**	**134.9**	**129.4**	dB

It is usual to model standard deviation σ in indoor environments as log-normal, just as before, but should be noted that, there is some evidence that it is itself more environment-dependent. We adopt σ from [11, (table 13.8)] with next values: 8 dB for residential and 10 dB elsewhere. Then, like above, for 90% reliability the log-normal fade margin L becomes 10 dB for residential area and 12.5 dB elsewhere. The inter-user link budget is given in table IV.

B. Cooperative Case Link Budget

The next step is to evaluate link budget for cooperative case between mobile and BS. For this case mobile transmitter characteristics remain the same as it is assumed for scenario of inter-user channel (Table IV), for BS that one is the same as for conventional case (Table III). Mobile receiver characteristics for DL also remained the same as for conventional case (Table III).

For BS receiver, compared to conventional case, some parameters are needed to be changed due to a virtual transmit diversity on UL. Spreading gain we keep the same 22 dB and 7 dB for voice and data 384 kbps respectively, as for case of inter-user channel, since the same data rate is transmitted in a twice less time.

TABLE IV: LINK BUDGET FOR INTER-USER CHANNEL

	Inter-user channel		
Path components	**12.2 kbps speech**	**PS 384 kbps**	**Units**
	Mobile		
Total transmitter power	0.25	0.5	W
Transmitter power on TCH	24	27	dBm
TX antenna gain	0	0	dBi
TX cable + connector loss	0	0	dB
TX Body loss	4	0	dB
Transmitter EIRP	20	27	dBm
	Mobile		
RX antenna gain	0	0	dBi
RX cable + connector loss	0	0	dB
RX Body loss	4	0	dB
Thermal noise density	-174	-174	dBm/Hz
Receiver noise figure	6	6	dB
Receiver noise density	-168	-168	dBm/Hz
Receiver noise power	-102.2	-102.2	dBm
Interference Margin	0	0	dB
Spreading gain	22	7	dB
Required Eb/No	8.5	7	dB
Receiver sensitivity	-115.7	-102.2	dBm
Diversity gain	0	0	dB
Fast fading margin	4	4	dB
Soft Handover gain, multicell	0	0	dB
Max. path loss	**127.7**	**125.2**	dB

TABLE V: LINK BUDGET FOR COOPERATIVE CASE

		Dowlink (target load=0.75)		Uplink (target load=0.5)		
	Path components	12.2 kbps speech	PS 384 kbps	12.2 kbps speech	PS 384 kbps	Units
Transmitter characteristics		**BS**		**Mobile**		
	Total transmitter power	40	40	0.25	0.5	W
	Transmitter power on TCH	33	43.6	24	27	dBm
	TX antenna gain	18	18	0	0	dBi
	TX cable+connector loss	2	2	0	0	dB
	TX Body loss	0	0	4	0	dB
	Transmitter EIRP	49	59.6	20	27	dBm
Receiver characteristics and margins		**Mobile**		**BS**		
	RX antenna gain	0	0	18	18	dBi
	RX cable+connector loss	0	0	2	2	dB
	RX Body loss	4	0	0	0	dB
	Thermal noise density	-174	-174	-174	-174	dBm/Hz
	Receiver noise figure	6	6	2	2	dB
	Receiver noise density	-168	-168	-172	-172	dBm/Hz
	Receiver noise power	-102.2	-102.2	-106.2	-106.2	dBm
	Interference Margin (=-10 log (1-Target load))	6	6	3	3	dB
	Spreading gain	25	10	22	7	dB
	Required Eb/No	6.7	5.2	-0.2	-2.7	dB
	Receiver sensitivity	-114.5	-101.0	-125.4	-112.9	dBm
	Diversity gain (Eb/No includes div. gain)	0	0	0	0	dB
	Fast fading margin (power control headroom)	0	0	4	4	dB
	Soft Handover gain, multicell	1	1	2	2	dB
	Max. path loss	**160.5**	**161.6**	**159.4**	**153.9**	dB
Urban area	Log-normal fade margin	10	10	10	10	dB
	Indoor loss	16	16	16	16	dB
	Allowed propagation loss	**134.5**	**135.6**	**133.4**	**127.9**	dB
Medium area	Log-normal fade margin	11.75	11.75	11.75	11.75	dB
	Indoor loss	11	11	11	11	dB
	Allowed propagation loss	**137.7**	**138.8**	**136.6**	**131.1**	dB
Residential area	Log-normal fade margin	11.75	11.75	11.75	11.75	dB
	Indoor loss	8	8	8	8	dB
	Allowed propagation loss	**140.7**	**141.8**	**139.6**	**134.1**	dB

The core difference between conventional and cooperative link parameters, which yields the advantage of a new method is an improved Eb/No. We consider the case when both users are on the edge of cell and have approximately similar uplink channels (target BLER=10^{-2} is satisfied), and equal transmit powers. Based on [6], the amount of improvement, which is dramatic for good inter-user channels, decreases as the inter-user channel worsens.

However, even with an inter-user channel that is much worse than the uplink channels, still achieved a significant improvement. In UMTS PC works very effectively and BLER is kept at or close to target value along the cell range. The used Eb/No values for conventional case are obtained from [8], which is derived from [9] and [10]. They correspond to BLER=10^{-2}. In order to choose new improved Eb/No for cooperative case, which will correspond to the same BLER=10^{-2}, we refer to [6]. Here figures present analytical and simulation results for various scenarios. Among them we chose the case with destination received diversity (in practice all macro cells, except some pico and micro, employee receive diversity), slow Rayleigh fading, equal average SNR uplink channels, 50% cooperation, and reciprocal inter-user channels with various average SNR [6, (3.5.2)]. Slow Rayleigh fading case is chosen, because we will reserve fast fading margin in link budget. Curves for this scenario shows BER versus channel SNR. Based on the same work, for slow fading the BLER is about one order of magnitude more than BER and in order to plot it versus Eb/No we should shift the *x*-axis by 10logR dB. Figure 3.8 in [6, (3.5.2)] shows six curves for: no cooperation, perfect, 20 dB, 10 dB and 0 dB inter-user channel. Taking in account that author used code rate R=1/4 in the simulation, the 10 dB SNR (4 dB Eb/No) of inter-user channel is more close to the required Eb/No then other used values for inter-user channel and it is worse case, since the better inter-user channel the more gain from cooperation. For target BLER 10^{-2} Eb/No the improvement in cooperation over non-cooperation is better than 4.2 dB. On the other hand, the required Eb/No for inter-user channel defined by us above is about 8 dB (7 dB and 8.5 dB) which corresponds to 14 dB of SNR. Therefore additional correction is needed by 0.5 dB and gain from cooperation in our case becomes 4.7 dB. Finally, the link budget based on a new Eb/No for cooperative case (conventional values are shifted by 4.7 dB) is given in Table V.

TABLE VI: CELL RANGES FOR COOPERATIVE AND NON-COOPERATIVE CASES.

		Conventional case		Cooperative case			Improvement (%)	
		12.2 kbps voice	384 kbps data	12.2 kbps voice	384 kbps data	Units	12.2 kbps voice	384 kbps data
Urban area, indoor	DL range	0.82	0.9	0.8	0.9	km		
	UL range	0.56	0.32	0.8	0.53	km		
	Cell range	0.56	0.32	0.8	0.53	km	**42.9**	**65.6**
area,	DL range	1.8	1.9	1.8	1.9	km		
	UL range	1.23	0.82	1.7	1.12	km		
	Cell range	1.23	0.82	1.7	1.12	km	**37.4**	**36.6**
Residen-tial area, indoor	DL range	4.9	5.3	4.9	5.3	km		
	UL range	3.3	2.25	4.6	3.1	km		
	Cell range	3.3	2.25	4.6	3.1	km	**39.4**	**37.8**

III. NUMERICAL RESULTS AND CONCLUSIONS

Now link budgets for conventional and cooperative cases and inter-user channel are ready to convert into cell radius. As was mentioned above, for this purpose we used Motorola Xlos propagation model. Except the inter-user range, the corresponding results are given below in Table VI. Referred to [11, (13.2.3)], which includes shadowing we extend it for use at 1950 MHz by adding 9 dB to the path loss and get the lower and upper limits of inter-user ranges for voice 12.2 kbps service: 60m and 88m and for 384 kbps data service: 57m and 84m respectively.

Now some conclusions could be drawn. First of all it should be noted, that cooperative strategy could be implemented with other radio access technology as well. The advantage of this selected kind of implementation is that an additional bandwidth is not required for cooperation, instead we divided UL transmission time equally between partners and increased mobile total output power twice, which in average is the same as for continues transmission case of frequency-division duplexing (FDD, excluding compress mode).

Cooperation leads to the additional increment of signaling flow on the air interface. For example, BS should know whether cooperation has taken place or not, if yes, whose bits each user is transmitting etc. In our work we neglected cooperative overhead, since it degrades performance unnoticeably.

As we can see from table III for conventional case, for both voice and data, system is clearly uplink limited. By

implementing new strategy the imbalance between DL and UL is decreased and cell ranges for cooperative partners for both services are prolonged significantly which are given in Table VI.

Introducing the new strategy we focused on cell range increment, but cooperation gives other advantages as well. For instance, for those mobiles which are within the cell range, closer than cell edge, in spite of output power increment by 3 dB during the half of time in cooperative mode, they transmit in average less power on the UL by at least 4.7 dB, therefore mobile battery consumption is reduced and UL interference also is decreased. Comparing BS receiver characteristics in tables 3 and 5 between traditional and cooperative modes it should be noticed that the receiver sensitivity is improved by 1.7 dB for each of services. It is important to note, that above showed gains for cooperative case would be better if distance between partners becomes less than calculated.

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Giorgi Tabuashvili was born in Tbilisi, Georgia, in 1962. He received his Master's degree in Electrical Engineering from the Georgian Technical University in 1985; and where, since 2009, he has been pursuing a Ph.D. degree in Telecommunications.

From 1988 to 1996 he was an Assistant Professor working in the Digital Communications Theory Department with the Georgian Technical University. Following that he was, from 1996 –1997, Deputy Head of the Technical Department at Goodwillcom Ltd. For the past 15-years Giorgi has been working in Magticom, and since 2004 he assumed the position of Director, Radio Frequency Planning and Optimization Department. His current research interests include channel coding, transmit diversity and user cooperation for wireless communications and he has coauthored the following papers: Coded Cooperation based on Punctured Convolutional Codes and Cooperative Generalized Concatenated Coding.

Development of Automation System for Room Lighting Based on Fuzzy logic Controller

Aryanto Hartoyo and Seno Darmawan Panjaitan

***Abstract*—This paper describes the development of fuzzy logic controller for room lighting system using AT89S51 microcontroller. The fuzzy logic system has two membership functions for the light sources as inputs and one membership function for the output. The first light source is from the outside and the second light source is available in the room. The other input to the control system is from the occupation sensor. The output membership function of the control system is used to determine the number of compact fluorescent lamp (CFL) that must be turned on. The control system will switch the CFL on or off according to the condition of the illuminance in the room. The room illuminance is based on Indonesian National Standard which is about 250 Lux. In case the room is empty, the controller will turn all lamps off. The result of experiment showed 23.9 % in power saving and 4.1 % in difference of control system output to the reference.**

***Index Terms*—Fuzzy logic, membership function, lighting system, microcontroller**

I. Introduction

In the life of human-being, lighting is something needed either night time or day time. However, human-beings always give a little attention only to the operation of the lamp, they always forget to switch the lamp off as the room is empty or to decrease the number of lamps to be switched on, if the incoming light to the room is going brighter. In general, the electricity consumption for the lighting will be around 25% - 50% [10]. Nowadays a great portion of our source of energy is from fossil energy or fuel that will be exhausted soon. So efficiency of lighting energy usage is an important effort to do by human being. One of the lighting energy efficiency researches is using lighting control method. The controller will control the number of lamps to be switched on while maintaining the suitable illuminance for the specific condition of the room. By the use of an automatic controller then lighting energy consumption can be reduced.

Based on the experience, knowledge and ability of learning, an operator can control some process successfully. Fuzzy logic implies the knowledge base and linguistic phrases is able to represent the operator work. There are many papers presented by researcher in fuzzy logic lighting control in [11-14] which were focused on power density or dimming in illumination level control. Nowadays, most of room lighting use Compact Fluorescent Lamp (CFL), because CFL is more efficient then incandescent lamp.

In this paper, fuzzy logic is proposed as the control method for a room lighting system with CFLs as the controlled objects. The number of lamps depends on the condition of the room function and the standard illumination level which was based on the Indonesia National Standard SNI 03-6197-2000 [15]. By using fuzzy logic controller, there are three benefits contributed, those are: (1) implementation of a low-cost control hardware by using microcontroller based system, (2) an automatic control system based on fuzzy logic with occupation and illumination sensing, (3) easiness of installation and expansion for a bigger system. There are two scopes of lighting control system design which are the hardware with a microcontroller based system and the software based on the fuzzy logic.

II. System Requirements

In order to perform the design process, some parameters and measurement method must be performed to fulfill the system requirements. The assignment and definition consist of:

A. Determination of Illumination Level for the Room

In this research the lighting control was puposed for a classroom function. According to SNI 03-6197-2000 [15], the illumination for classroom is 250 lux.

B. Measurement and Calculation of Room Parameter

The room parameters are wall color, reflection factor, room area and height.

C. Lamp Position Arrangement and Measurement of Illumination Uniformity

Illumination uniformity is an important factor for human being eyes in order that eyes fatigue can be avoided. One of the methods to achieve illumination uniformity is by fulfilling the spacing criterion (SC). SC is the ratio between center of luminaries and the distance to the work plane or mounting height. SC is set 1.5 means the maximum distance between every light is equal to 1.5 times mounting height.

D. Calculation of the Number of Lamps in the Room

This calculation was to fulfill the illumination level of the room, i.e. 250 lux. The formula used in the calculation is:

$$E = \frac{\Phi \times CU \times LLF}{A} \quad (1)$$

where,

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The authors are with the Electrical Engineering Department, Faculty of Engineering, Tanjungpura University, Pontianak 78124, Indonesia (e-mail: hartoyoanto@yahoo.co.id,seno.panjaitan@untan.ac.id,senopanjaitan@gmail.com).

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