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Factorial Design Analysis for Quality of Video on MANET

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***Abstract*—**The quality of video transmitted by mobile ad hoc networks (MANETs) can be influenced by several factors, including protocol layers; parameter settings of each protocol. In this paper, we are concerned with understanding the functional relationship between these influential factors and objective video quality in MANETs. We illustrate a systematic statistical design of experiments (DOE) strategy can be used to analyze MANET parameters and performance. Using a 2^k factorial design, we quantify the main and interactive effects of 7 factors on a response metric (i.e., mean opinion score (MOS) calculated by PSNR with Evalvid package) we then develop a first-order linear regression model between the influential factors and the performance metric.

***Keywords*—**Evalvid, full factorial design, mobile ad hoc networks, ns-2.

I. Introduction

An ad hoc mobile networks (MANETs) consists of a collection of mobile nodes that self-configure to autonomously operate a network without any established infrastructures [1]. MANETs have advantages and benefits of allowing people and devices to seamlessly internetwork in areas without pre-existing communication infrastructure. MANETs are widely deployed in applications including disaster recovery environments, group wares, and games. In these days, video related application services including real-time video streaming and video on demand (VOD) become available and get more and more popularity [2].

Whereas MANETs have the advantages that can provide with ability of which can interconnect mobile nodes without any infrastructure, MANETs have disadvantages that cannot provide with stable communication performance. In order to alleviate the disadvantages, protocol stacks of MANETs (e.g., PHY, LL, MAC, routing) need to be optimized. Effect of each protocol to performance of MANETs is interacted with each other. Therefore, researches for cross-layer design and optimization of MANETs have been conducted [2]–[5]. The objective of the cross-layer design mainly has focused on optimization of the performance metrics (e.g., throughput, loss rate, delay, jitter) or voice quality. On the other hand, the objective of this paper is to optimize the video quality on MANETs. Recently, advance of communication technologies allow video application to be enable in the mobile devices. Video service applications such as video on demand (VOD) and real-time video streaming need high performance network (i.e., fast packet transmission, low packet loss rate, small one-way packet delay). Therefore, providing video services in MANETs are more difficult than providing other kind of network services. When sufficient network performance for real-time video services is not guaranteed, distortions during transmission can result in a degradation of visual quality. For video service applications viewed by human beings, the ultimate and correct method of qualifying visual quality of the video is through subjective evaluation to investigate mean opinion scores (MOS). However, the subjective evaluation usually needs inconvenient procedures that are time-consuming and expensive. As an alternative to subjective evaluation, an objective quality assessment is developed to automatically predict perceived image quality [6], [7].

One of the simplest and most widely accepted objective quality assessment metrics is the mean squared error (MSE). The MSE can be simply calculated by averaging the squared intensity differences between reference and distorted image pixels, along with the peak signal-to-noise ratio (PSNR) [6]. The objective quality assessment uses MSE and PSNR to predict MOS.

The objective of this paper is to analyze the protocol stack of MANETs and their parameters using a statistical factorial design method. Section II deals with an experimental design for ns-2 simulation. In Section III, the subjective quality metric, MOS, is calculated by comparing the PSNRs of reference video and simulated video, PSNR to and analyzed with statistical methods. Finally, Section IV presents conclusions with the contributions of this paper and further research.

II. Experimental Design for Simulation

This section presents the MANET environment and video quality evaluation procedures deployed in the simulation. We use ns-2 simulator and Evalvid package to run simulation. Evalvid is an add-on module of ns-2, one of the most popular network simulators, to enable video evaluation function [8]. We use factorial design to investigate the joint effect of the factors on a response in the simulation experiments. Especially, we consider only two levels for each factor. This is called a 2^k factorial design. Where the number of factors is k and eachfactor has two levels, the design requires 2^kexperimental runs.The 2^kdesign can be useful when a lot of factors need tobe investigated.

A. Response Variable

In this paper, we consider MOS predicted from objective metrics calculated by pixels of reference and distorted (or transmitted) images as a response variable, y. The most widelyused objective metric is the peak signal-to-noise ratio

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(PSNR).

PSNR can be simply calculated by the mean squared error (MSE) which means the difference between the pixels of original image and distorted image. For example, let the resolution of a monochrome image be m × n. Where pixels of the original and the distorted images are O(i, j) and D(i, j), respectively, the MSE can be calculated as shown (1).

$$\mathrm{MSE} = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[O(i,j) - D(i,j)]^2 \quad (1)$$

Equation (2) shows the PSNR calculated by the MSE where MAXo is the maximum number of levels used to quantize each pixel of the original image.

$$\mathrm{PSNR} = 10 \cdot log_{10}(\frac{MAX_o^2}{MSE}) \quad (2)$$

B. Factor Variables

Mobile nodes of MANET consist of hierarchical communication protocol layers. Routing protocol and Medium access protocol (MAC) plays an important role in transmission performance of MANETs. Recently, IEEE 802.11 series protocols gain widely acceptance in MANET MAC layer. The parameter setting of the routing and MAC protocols can significantly affect performance of MANETs as well as video quality. The MANET topology considered in this paper is rectangular area of 1000m × 1000m, and the MANET has 20 or 40 mobile nodes whose average speed is 2 or 10m/s. One mobile node sends a VOD streaming traffic to another mobile node. In addition, 4 or 10 nodes send background TCP traffic. The packet size of each traffic is 512 or 1024 bytes.

TABLE I
FACTORS OF 2^7 FACTORIAL DESIGN EXPERIMENT

Name	Description	Level (-)	Level (+)
packetSize	Packet size of link layer	512	1024
art	Active route timeout	5	15
rwt	Maximum router request wait timeout	5	15
rt	Number of Maximum retransmissions	1	5
nn	Number of nodes	20	40
speed	Average speed of nodes	2	10
bt	Number of background traffic	4	10

C. Factorial Designs

The factorial design requires 128 (2^7) simulation runssince the 7 factors are considered in this paper. In addition, one simulation run is conducted at center point in order to investigate pure second-order or quadratic effects. Therefore, the total number of simulation runs is 129.

D. Video Quality Evaluation

In this simulation, the source video is in YUV420 format with a resolution of CIF (352 × 288), a frame rate at 30 fps, and a playtime of 35.5 seconds. A sample snapshot image of the source video is shown in the Fig. 1.

Fig. 1 Snapshot image of the source video clip

The procedures of the video quality evaluation using ns-2 simulation are depicted in Fig. 2.

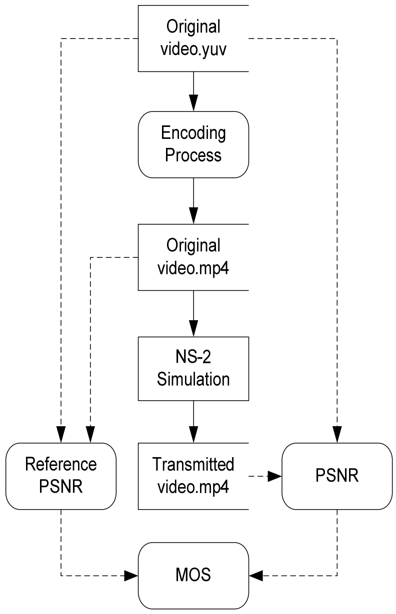

Fig. 2 Procedures of the ns-2 simulation

In the first step, the original video of YUV format is encoded to the image ofmp4 type. The MANET transmission is simulated by ns-2 in the second step. Finally, two PSNRs are calculated. One is from the difference between the original video and the encoded original video, and the other is from the difference between the original video and the transmitted encoded video. The MOS is calculated using the two PSNRs.

III. DATA ANALYSIS

In this section, we analyze the simulation results by analysis procedures for a $\mathbf{2^k}$ design with a statistical software package (Minitab v. 16). While the complete model of a $\mathbf{2^k}$ factorial design can contain $\mathbf{2^k}-1$ effects, we consider k main effects and $\binom{k}{2}$ two-factor interactions in this paper.

First of all, we examine a normal probability plot of the estimates of the effects (see Fig. 3). Significant effects which have nonzero means will not lie along the straight line whereas the effects plotted on the straight line can be statistically negligible. That is, the four main effect, A, D, E, and F, and six two-factor interactions are statistically significant.

Fig. 4 shows a) the normal probability plot of the residuals, b) the plot of the residuals versus the predicted fitted MOS, c) the histogram of the residuals, and d) the residuals sorted by the observation order. These plots present normality and equality of variance. Therefore, the analysis needs no data transformation.

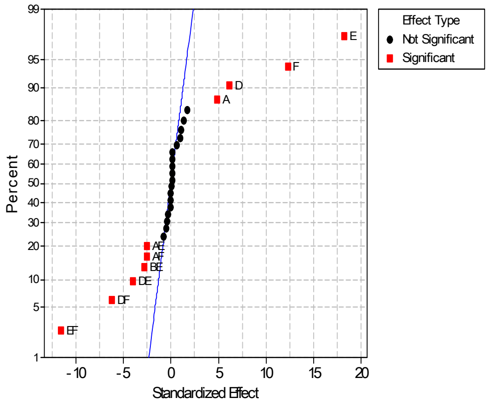

Fig. 3 Normal plot of the standardized effects for MOS (α = 0.05)

We can estimate the main effects and the two-factor interaction effects as shown in Table II. The terms of main effects (packetSize, rt, nn, and speed) and the term of interaction (packetSize*rt, packetSize*nn, packetSize*speed, rt*nn,rt*speed, nn*speed) are significant. In addition, the term of center point provides the evidence of linearity of the model.

The main effects of the significant factors are plotted in Fig. 5. All four effects are positive. Fig. 4 obviously indicates that the response (i.e., MOS) becomes desirable as each factor has the high level. However, it is necessary to examine any interactions to obtain valid conclusion.

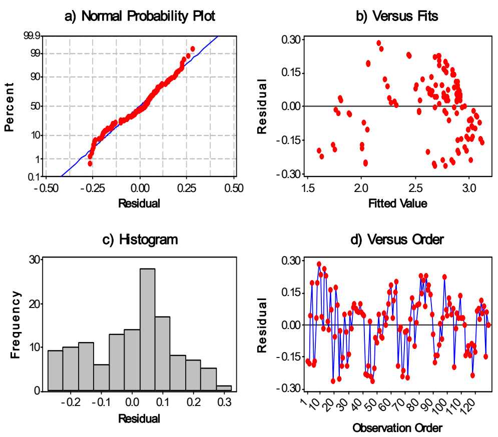

Fig. 4 Residual plots for MOS

Fig. 6 shows the interaction between the significant factors. We can find that all the interactions except nn* speed is negligible. Note from the interaction of nn*speed that the speed effect is very small when the nn effect is at the high level. Therefore, every interaction has little effect.

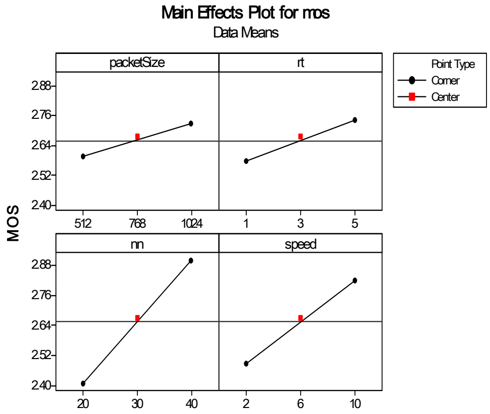

Fig. 5 Main Effects plot for MOS

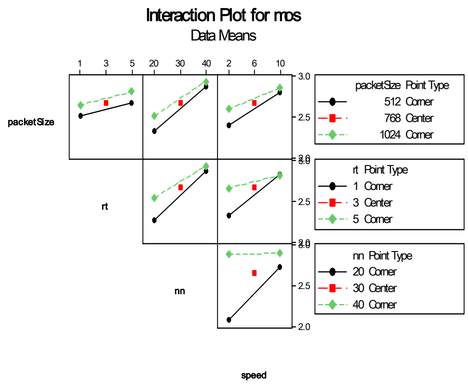

Fig. 6 Interaction plot for MOS

The data analysis presents the insight into the relationship between the perceived quality of video and the factors including MANET parameters. The effective factors (i.e., statistically significant effects) are the packet size, retransmission time out, the number of mobile nodes in the Manet area, and the average speed of the nodes. In these factors, only the retransmission time out is a controllable factor whereas the other factors are uncontrollable. The interaction plot shows that the main effect of rt at high level is desirable. However, the effect of rt at low level is slightly desirable when the main effect of speed is at high level. The model of significant effects is denoted by coded variables in the (3).

$$\hat{y} = 2.658 + 0.066 packetSize + 0.083 rt + 0.247 nn + 0.166 speed - 0.038 art \cdot nn - 0.055 rt \cdot nn - 0.085 rt \cdot speed - 0.156 nn \cdot speed \quad (3)$$

IV. Conclusion

We quantify the main and interactive effects of seven factors on a response metric (i.e., mean opinion score (MOS) calculated by PSNR with Evalvid package), and then develop a first order linear regression model between the influential factors and the performance metric. The data analysis presents the insight into the relationship between the perceived quality of video and the factors including MANET parameters. The terms of main effects (packetSize, rt, nn, and speed) and the term of interaction (packetSize*rt, packetSize*nn, packetSize*speed, rt*nn, rt*speed, nn*speed) are significant

TABLE II
ESTIMATED EFFECTS AND COEFFICIENTS FOR MOS (CODED UNITS)

Term	Effect	Coef	SE Coef	T	P
Constant		2.658	0.014	196.00	0.000
packetSize	0.131	0.066	0.014	4.85	0.000
art	0.028	0.014	0.014	1.01	0.314
rwt	0.003	0.002	0.014	0.12	0.904
rt	0.166	0.083	0.014	6.12	0.000
nn	0.493	0.247	0.014	18.18	0.000
speed	0.333	0.166	0.014	12.27	0.000
bt	-0.011	-0.005	0.014	-0.39	0.695
packetSize*art	-0.001	-0.001	0.014	-0.05	0.962
packetSize*rwt	-0.008	-0.004	0.014	-0.29	0.776
packetSize*rt	0.005	0.003	0.014	0.20	0.842
packetSize*nn	-0.067	-0.034	0.014	-2.49	0.015
packetSize*speed	-0.068	-0.034	0.014	-2.51	0.014
packetSize*bt	0.004	0.002	0.014	0.14	0.893
art*rwt	-0.001	-0.001	0.014	-0.05	0.961
art*rt	0.018	0.009	0.014	0.65	0.520
art*nn	-0.076	-0.038	0.014	-2.80	0.006
art*speed	-0.021	-0.010	0.014	-0.76	0.451
art*bt	0.047	0.024	0.014	1.74	0.084
rwt*rt	0.004	0.002	0.014	0.14	0.887
rwt*nn	-0.013	-0.006	0.014	-0.46	0.645
rwt*speed	0.001	0.001	0.014	0.05	0.958
rwt*bt	0.003	0.002	0.014	0.12	0.907
rt*nn	-0.109	-0.055	0.014	-4.02	0.000
rt*speed	-0.169	-0.085	0.014	-6.23	0.000
rt*bt	-0.002	-0.001	0.014	-0.07	0.946
nn*speed	-0.312	-0.156	0.014	-11.50	0.000
nn*bt	0.038	0.019	0.014	1.39	0.167
speed*bt	0.029	0.014	0.014	1.06	0.291
Ct Pt		0.016	0.154	0.11	0.916

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