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Determination of Efficient bandwidth utilization During Multicast using Data Envelopment Analysis

Joseph Stephen Soja
Department of Electrical and Computer Engineering,
Ahmadu Bello University Zaria, Kaduna State

Suleiman Mohammed Sani
Department of Electrical and Computer Engineering,
Ahmadu Bello University Zaria, Kaduna State

Abdoulie Momodou SunkaryTekanyi
Department of Electrical and Computer Engineering,
Ahmadu Bello University Zaria, Kaduna State

ABSTRACT
Data Envelopment Analysis (DEA) is an operational research tool that is used for measuring the performance efficiency of an algorithm or organization. In this paper, DEA is applied on the simulation results of an Improved Network Coding Algorithm (INCA) with two and three performance in order to establish the performance efficiency of the two algorithms in terms of bandwidth utilization during video conferencing over a wireless network. Most researches which focus largely on determining the effectiveness of the INCA in terms of bandwidth consumption during video conferencing. However, this approach which uses DEA, the simulation results showed that the INCA with two parameters is the most cost-Efficient algorithm in terms of performance than the INCA with three parameters.

General Terms
Data Envelopment Analysis, Improved Network Coding Algorithm, Multicast and Performance Efficiency.

Keywords
Data Envelopment Analysis, Efficiency, Constant Return to Scale, Bandwidth and Decision Making Unit.

1. INTRODUCTION
Data Envelopment Analysis (DEA) is a linear programming based technique for measuring the relative performance of an algorithm or organization with multiple inputs and outputs [1].The DEA method was first introduced by [2]and is called Charnes, Cooper, and Rhodes (CCR) model. There is an increasing concern with measuring and comparing the efficiency of algorithms for efficient and effective bandwidth utilization during multicast [3]. Video conferencing over wireless networks is one among the most salient application of multicast that is receiving significant attention because of its wide range of application in various fields of learning. It is the process of group discussion where participants from different part of the world share ideas over the internet. The increased demand to incorporate video data into telecommunications services for conferences, meetings, business transactions and home games, have made digital video technology a necessity [4]. Telecommunication technology has enhanced human lives in many multimedia applications such as in electronic learning, video conferencing, electronic library, online shopping, video on demand and so on [5]. Face-to-face interactions at meetings are the best meaningful decision making technique, but it is sometimes difficult to assemble participants at the same time in a single place [6].

The major challenges facing multimedia application today is the high cost of bandwidth and energy consumption. Optimizing bandwidth usage in other to lower the amount of data transmitted over the network helps to reduce network congestion and increase network performance. Compression and encryption, optimal protocols and video compression aid in the optimization of bandwidth during video conferencing reduce network traffic and add a level of security to the data stream. Centralized video conferencing system requires core entity to receive and redistribute streams and this device is known as a Multipoint Control Unit (MCU). The MCU terminates all voice and video media streams in a conference.

Video conferencing applications are key multicasting alternatives for group meetings and for costs savings as well [7]. Video conferencing has been a method of supporting group communication which allows transmission and routing of packets to multiple destinations using fewer resources. This method involves routing packets to a set of receivers; r_1, $r_{2,}\ldots r_n$ nodes [8, 9]. The method is essentially a televised telephone call, in which both audio and visual signals are transmitted both ways.

These signals are transmitted via the internet and processed into readable format by equipment called a codec. Video conferencing has the following components: display, cameras, microphones, amplifiers, speakers, echo cancellers, networks, user interface, cables, peripheral equipment and codec.

Data applications tend to be very demanding in the utilization of network bandwidth during video conferencing. Congested queues are the primary contributors to packet delay and loss in a packet network. The bandwidth required to send the video is higher than the required bandwidth for receiving the video [10]. Webcam video is used primarily for video conferencing. The streaming video file feature is a video that is encoded and streamed to other meeting participants as shared content during a meeting [11].

Electronic learning over the Internet is also taking the center stage to replace classroom training and instructional meetings, where a presenter and the participants can demonstrate physical apparatus and processes in real-time, addressing questions as they arise [12]. A good example of video conferencing concept is shown in Figure 1. Participants listen to one another from different part of the world and share ideas. In this video conferencing, only one person talks at a time while others listen and they can as well give their individual contribution.

Figure 1: Video Conferencing Concept[13]

The efficiency of two multicast algorithms over wireless network was studied by [3]. In the study, the simulation results clearly showed that the Network Coding Algorithm (NCA) outperformed the Multicast Incremental Power Algorithm (MIPA) for cost efficient multicast. However, the NCA was only compared with the MIPA and the efficiency of the NCA with respect to the other algorithms was not determined.

The scope of the research was further extended by applying slack variable to determine how strong or weak was the efficiency of the NCA[14]. Simulation results showed that the NCA was strongly efficient in most of the results obtained.

Multi-party video conferencing aimed at achieving optimal bandwidth sharing by investigating two cross swarm bandwidth sharing scenarios was implemented by [15]. The study focused on two sharing scenarios: swarms were independent and peers from different swarms shared the same pools. Also, swarms were cooperative and peers in an abundant bandwidth swarm shared their bandwidths with peers in a limited bandwidth swarm. A pertinent review of some multicast algorithms over wireless networks with a view of identifying areas for further research was also studied by[16].

To the best of my knowledge, the studies carried out so far have not addressed the application of DEA to determine the performance efficiency of the INCA with two and three parameters during video conferencing and hence the motivation of this research. This research is an extension of research carried out by [17, 18],where the study established that the INCA is the most cost-effective in terms of bandwidth utilization when compared with NCA.

There is a need to find the efficiency of the two algorithms (INCA with two parameters and INCA with three parameters). This paper focuses on the application of DEA using Constant Return to Scale Model (CRS) to determine the Performance efficiencies of INCA with two and three parameters in terms of bandwidth utilization over wireless network. The INCA with two and three parameters was proposed by [18]. Bandwidth and energy consumption over wireless networks are major factors that discourage group communication and there is an urgent need to be addressed this problem in order to achieve cost efficient multicast.

To carry out this research, the DEA program is run using input orientated on the simulation results obtained by [17] to determine the efficiency of the two algorithms. Already, it had been established that the simulation results obtained by [18] showed that the INCA with three parameters was more effective than that of two parameters.

The paper is organized as follows. Section II contains DEA and its techniques. Section III presents DEA mathematical model. Section IV covers DEA simulation results and Section V concludes and summarizes the paper.

2. BASIC OF DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is an operational research tool that is widely used by managers for evaluating the performance of a set of algorithms or peer entities called Decision Making Units (DMUs) which convert multiple inputs into multiple outputs. It has been used for evaluating the efficiency of entities because it requires very few assumptions [19]. It is a mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates on the performances of various entities. DEA is an objective evaluation technique because of its forthright linear programming-based calculation procedure [20]. DEA consist of entities called the Decision Making Units (DMUs) which are used for evaluating the performance of the entities and to convert inputs into outputs. In this context, assume that there are k DMUs to be evaluated and each DMU consumes different amounts of m different inputs to produce n different outputs. DMU_j consumes amount x_{ij} of input i and produces amount y_{rj} of output r. The value of input and output consumed are assumed to be greater than zero [21]. DEA focuses on Constant Return to Scale and Variable Return to Scale Model.

2.1 Constant Return to Scale

This is an applicable when all the DMU's are operating at an optimal scale. This usually results to measures of Technical Efficiency (TE) which are confounded by Scale Efficiency (SE). CRS DEA model can be extended to account for variable return to scale[19].

2.2 Variable Return to Scale

It tends to address the setback of CRS. The use of Variable Return to Scale (VRS) specification will permit the calculation of Technical Efficiency (TE) devoid of the TE effects. CRS can easily be modified to account for VRS by adding a complexity constraint[19].

3. DEA MATHEMATICAL MODEL

DEA evaluates the efficiency of a set with N peer entities called Decision Making Units (DMU) which convert multiple inputs into multiple outputs. The basic measure of efficiency is the ratio between one output and one input, which can be written in[21] as:

$$\text{Efficeincy} = \frac{outputs}{inputs} \quad (1)$$

However, equation (1) is normally not adequate to be applied in the real world problem, where there are multiple inputs and outputs. To take care of this problem, DEA was employed as a common measure for relative efficiency by taking into consideration the weighted sum of output divided by the weighted sum of input in[22] as:

$$\text{Efficeincy} = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs} \quad (2)$$

When the usual notation is included equation (2) is written by[23] as:

$$\text{Efficiency of unit j} = \frac{u_1 y_{1j} + u_2 y_{2j} + \dots}{v_1 x_{1j} + v_2 x_{2j} + \dots} \quad (3)$$

where:

u_1 = weight given to output 1

y_{1j} = amount of output 1 from unit j

v_1 = weight given to input 1

x_{1j} = amount of input 1 to unit j

The principle behind this model is linear programming approach, which is definite as a problem of maximizing or minimizing a linear function subject to linear constraints. Equation (3) shows the efficiency of unit j when all the DMU's are operating at an optimal scale. For each of the DMUs, the ratio of the sum of the weighted output factors divided by the sum of the weighted input factors is strictly less or equal than 1 [24].

$$Max \sum_{k=1}^{s} v_k y_{kp}$$

s.t

$$\sum_{j=1}^{m} u_j x_{jp} = 1 \quad (4)$$

$$\sum_{k=1}^{s} v_k y_{kq} - \sum_{j=1}^{m} u_j x_{jq} \le 1$$

$$v_k, u_j \ge 0$$

This model is run n times to find the relative efficiency score of n DMUs

where, k= 1 to s, j =1 to m, q =1 to n and

y_{kq} = amount of output k produced by DMU q

x_{jq} = amount of input j utilized by DMU q.

v_k = weight given to output k

u_j = weight given to input j

4. DEA SIMULATION RESULTS

Simulation results are obtained for the bandwidth consumed during video conferencing for different number of nodes generated at random. The cost of bandwidth consumed for different groups of participants were also obtained. In this work, the outputs include the number of participants while the input includes the associated cost of bandwidth consumed during video conferencing over the wireless network. The DEA was run using the simulation results obtained from Tables 1, 2 and 3 for 20, 50 and 60 nodes generated at random. The respective efficiency of 2, 3, 4, 5, 6, 7, 8, 9 and 10 participants were obtained. Figure 2 shows the flow chart of DEA simulation.

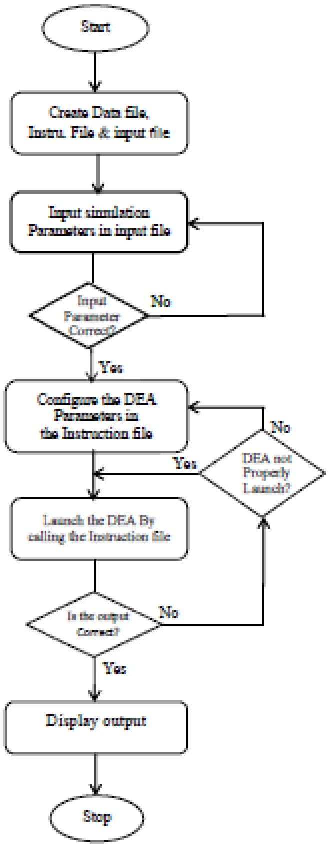

Figure 2: Flow Chart of DEA Simulation

To begin the simulation, data file, instruction file and output are created as shown in Figure 2. The instruction file contains all the relevant DEA parameters that are subject to configuration based on what the researcher intents to achieve. On the other hand, the data file is a file containing all the input values that are used for the simulation and the output file is a file that contains the output results of the DEA simulator. The DEA program is launched by calling the instruction file after configuration and the instruction file takes the content of data file as input and displays the results at the output file. This process continues for different values of INCA with two and three parameters for all randomly generated nodes. Tables 4, 5 and 6 show the simulation results obtained.

Table 1: Bandwidth Consumption for 20 NodesGenerated at Random

Number of participants	Effective Cost of bandwidth consumption in Mbps	
	INCA with two parameters	INCA with three parameters
2	0.3405	0.1571
3	1.5047	1.4453
4	1.6769	1.5297
5	2.2611	1.2306
6	3.2449	2.4076
7	4.9350	4.3894
8	5.5823	5.4192
9	6.2030	5.9324
10	8.4356	7.2994

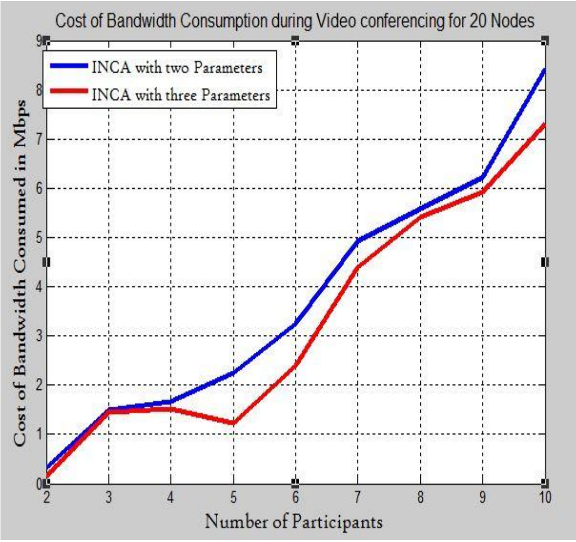

Figure 2: Bandwidth Consumption for 20 NodesGenerated at Random.

From Figure 3, the consumption of bandwidth during video conferencing was minimized by 12.7% when INCA of three performance metrics was compared with INCA of two metrics as shown in Table 2. Figure 4 shows a graph of the bandwidth consumption during video conferencing minimized to 11.1% when INCA with three performance metrics was compared to the INCA with only two performance metrics.

Table 2: Bandwidth Consumption for 50NodesGeneratedat Random

Number of Participants	Effective Cost of bandwidth consumption in Mbps	
	INCA with two parameters	INCA with three parameters
2	0.7506	0.2555
3	1.6129	1.0598
4	2.0116	1.6066
5	2.8540	2.8184
6	4.3289	4.3147
7	5.9323	5.0145
8	6.4192	6.2312
9	6.9220	6.0914
10	7.8556	7.0058

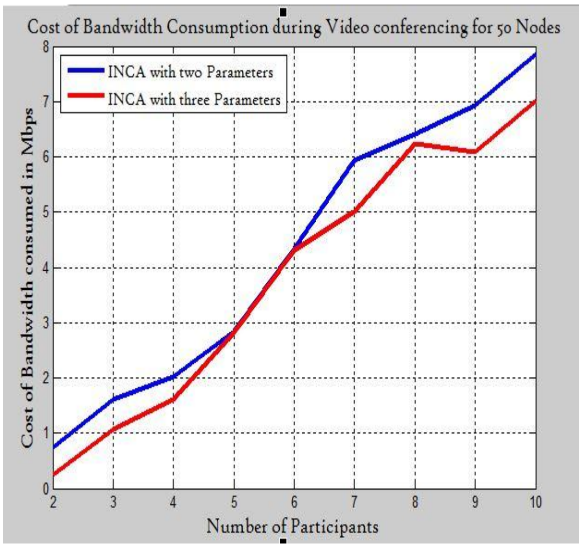

Figure 4: Bandwidth Consumption for 50 Nodes

Generated at Random

Table 3: Effective Bandwidth Consumption for 60Nodes Generated at Random

Number of participants	Effective cost of bandwidth consumption in Mbps	
	INCA with two parameter	INCA with three parameters
2	1.8676	1.0772
3	2.5694	1.1341
4	1.4818	1.2087
5	4.7344	4.2347
6	4.2993	4.1223
7	3.7835	3.1230
8	5.9203	5.8159
9	6.2568	5.3186
10	6.9860	6.5559

As shown in Figure 5, the INCA which has three parameters minimized the rate of bandwidth consumption to 16.3% when compared with the INCA having two parameters.

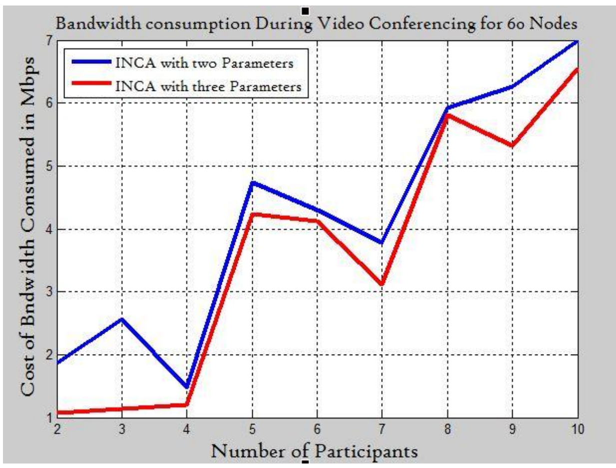

Figure 5: Bandwidth Consumption for 60 NodesGenerated at Random

Table 4: Efficient Bandwidth Consumption for 20 Nodes Generated at Random

Number of participants	Cost Efficiency	
	INCA with two parameter	INCA with three parameters
2	1.000	1.000
3	0.339	0.163
4	0.406	0.205
5	0.376	0.319
6	0.315	0.196
7	0.241	0.125
8	0.244	0.116
9	0.247	0.119
10	0.202	0.108
Mean	**0.375**	**0.261**

Table 5: Efficient Bandwidth Consumption for 50Nodes Generated at Random

Number of participants	Cost Efficiency	
	INCA with two parameter	INCA with three parameters
2	1.000	1.000
3	0.698	0.362
4	0.746	0.318
5	0.657	0.227
6	0.520	0.178
7	0.443	0.178
8	0.468	0.164
9	0.488	0.189
10	0.478	0.182
Mean	**0.611**	**0.311**

Table 6: Efficient Bandwidth Consumption for 60 Nodes Generated at Random

Number of participants	Cost Efficiency	
	INCA with two parameter	INCA with three parameters
2	0.397	0.561
3	0.433	0.353
4	1.000	1.000
5	0.391	0.357
6	0.517	0.440
7	0.685	0.677
8	0.501	0.416
9	0.533	0.511
10	0.530	0.461
Mean	**0.554**	**0.531**

4.1 Results and Discussions

Two types of cost performance metrics are discussed in this paper. The cost effectiveness of the two algorithms is showed in Tables 1, 2 and 3 and from the simulation results obtained, the Improved Network Coding Algorithm (INCA) with three performance parameters is the most cost effective algorithm because it significantly achieved a reduction in bandwidth consumption during video conferencing. Simulation results also showed that the INCA with three parameters minimized average bandwidth consumption by 11.1%, 12.7% and 16.3% when compared with the INCA using only two parameters for all the number of nodes generated at random during video conferencing. This is evident from the simulation results obtained from Tables 1, 2 and 3. When interpreting the simulation results obtained from Tables 1, 2 and 3 graphically, Figures 2, 3 and 4 clearly indicate that the INCA with three parameters significantly minimized the consumption of bandwidth during video conferencing.

Similarly, the cost efficiency of the two algorithms is showed in Tables 4, 5 and 6. We carried out the simulation using Constant Return to Scale (CRS) assumption by considering all DMU's operating at an optimal scale. Simulation results showed that the INCA with two parameters is cost efficient during video conferencing when benchmarked with the INCA with three parameters. As shown in Tables 4,5 and 6, the mean efficiency of INCA with two parameters is 0.375, 0.611 and 0.554 as compared with 0.261, 0.311 and 0.531 values of the INCA with three parameters.

The significant contribution of this research to the existing body of knowledge is the application of DEA to determine the performance efficiency of the two algorithms. Recent works focused largely on the effectiveness of some multicast algorithms over wireless networks as the case was with[17].

5. CONCLUSION

The performance efficiencies of the INCA with two and three parameters using DEA as an efficiency measuring tool were achieved for the two multicast algorithms based on the network effectiveness. The findings showed that the INCA with two parameters performs better than the INCA with three parameters for only cost-efficient multicast. In reality, a more efficient network will consume lower bandwidth than inefficient network with a better quality of service.

This new way of evaluating the cost-efficiency of multicast algorithms over wireless network is receiving significant attention, most especially, in the research carried out by [3]. This will save a lot of resources and time as the world has become a global village. Further work should consider the application of DEA using Variable Return to Scale (VRS) assumption.

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