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An Analogy of a Network to an Electro Hydrodynamic Fluid Flow to Analyze the Energy Required for Transmitting a Packet in a Network Susceptible to Multiple Failures

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Abstract: Computer networks have become pervasive to human life and now, people are inseparable from connectivity. The world's networking communities have been constantly raising the bar of standards to provide the best possible service to their users. Every packet drop is treated as a blunder and a game ender by the companies. Standards lead to organizations that govern the service rules and policies, penalize the companies heavily if packets are lost, connections are severed mid-conversation. This makes the companies spare no expense into developing smarter and faster rerouting methods, packet retransmission protocols. The observation of these systems leads to believe that the system is modeled after an electro hydro dynamic fluid flow through a charged medium. In this paper the analogy and the analysis of the energy spent for rerouting packets in case of node failure, is presented in its complete mathematical form.

Key words: **Electro hydrodynamics, Packet loss, Computer Network, Packet transmission**

I. INTRODUCTION

The idea of a network as a fluid may not be the first or the last. However, the analysis of energy required to overcome multiple packet losses in a network is done only using the network parameters so far. In this paper, an intuitive approach to analyze the energy requirement of a network to overcome packet losses is done using a fluid flow analog of a network using Rayleigh equation[2]. In this approach, the energy required is derived from the basic state of the network where the net energy required for the transmission (source) and the net energy at the receiver (sink) are assumed to be equal.

II. LITERATURE REVIEW

This paper is a result of study of various research works in the field of fluid dynamics that have made the perspective of the authors about the analysis similar to that of a computer network with faults. It is a well established fact that in Fluid Mechanics, a comprehensive stability analysis is a prime requirement to understand the physics of fluid flow.

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Jolly and Melcher [1] have shown that the same situation prevails in electro hydrodynamic (EHD) fluids during interaction of a poorly conducting fluid in the presence of an electric field where the flow of the fluid affects the developed fields and the applied field influences the fluid flow. Orr-Sommerfeld equation has been used extensively in viscous flow and Rayleigh equation in inviscid flow, in the literature [2], [3], [4]. This work enhances the understanding of conditions triggering the transition of laminar flow to turbulent flow. The hydrodynamic stability of heterogeneous inviscid fluid has been studied in detail by Taylor[5], Goldstein [6], Synge [7] and Miles [8] and Howard [9] because of its applications in atmospheric and oceanographic sciences. These hydrodynamic stability problems in homogeneous viscous fluids have been extended to hydro magnetic stability by Stuart [10] and Lock [11]. This was done to use magnetic field to suppress the onset of instability. Later, Rudraiah[12][13][14] etal further continued the work of Synge [7] on an electrically conducting heterogeneous inviscid fluid in the presence of a transverse magnetic field and this work establishes the basis for the present work considering a network as a fluid through which packets travel like particles that have been energized using longitudinal electrodes and they're dropped or their motion is adversely affected by noise, power loss etc that are simulated by transverse electrodes. Kelvin-Helmholtz instability (KHI) and Richtmeyer-Meshkov instability (RMI) caused by sheer and shock at the interfaces have been analyzed in detail by Rudraiah [15]. Melcher and Taylor [5] and Lee et al [16], Lee [17], Roberts [18], Jolly and Melcher [1], Rudraiah etal [19] have also further improved the work by studying the stress at the interface of two fluids for EHD fluid flow. Their work assessed convective EHD instabilities. However till recently Baygents and Baldessare [20] investigated EHD stability in a thin fluid layer with an electrical conductivity gradient assuming the base flow to be noiseless such a system was not given any importance. In academic research conducted by Reynolds [21] and Orr [22] the functional parameters proposed to assess EHD fluid flow are the momentum and kinetic energy. These parameter computations have been extended to fluid flow under a magnetic field through a porous medium by Rudraiah [23]. Malkus and Veronis [24] studied the impact of EHD in ionosphere and storms. Further, the studies of EHD concentrated on thunder storms and their formation.

The thermal factors causing them etc.

However, all the studies limit themselves to the assessment of the EHD stability and its applications to larger atmospheric systems. In this paper, an attempt has been made to assess a computer network as an EHD flow with electrodes at multiple points causing change in potential to induce losses.

III. METHODOLOGY

For this research work, an analogous of a network in the following physical form is considered.

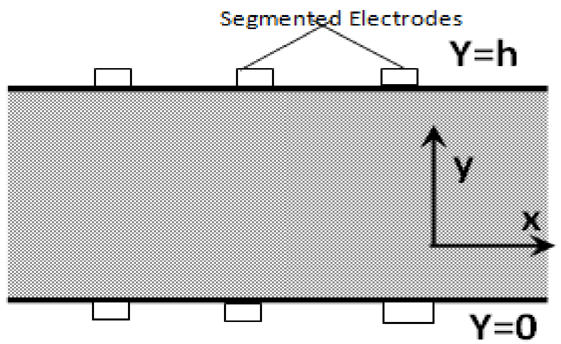

Figure 1. The physical analog of the network depicting node failure inducing energies as electrodes

The research work, developed a simple initial analog of a network for the fluid flow model shown in Figure 1. In the model the particle movement happens through the grey area which is assumed as the channel where the packets travel. The segmented electrodes are assumed to be the source of noise and/or power loss or any other obstacle due to which a packet can be lost. The expected direction for motion of the packet is X where as any deviation from it has to be nullified by external energy supplied to the packet from an XY vector direction.

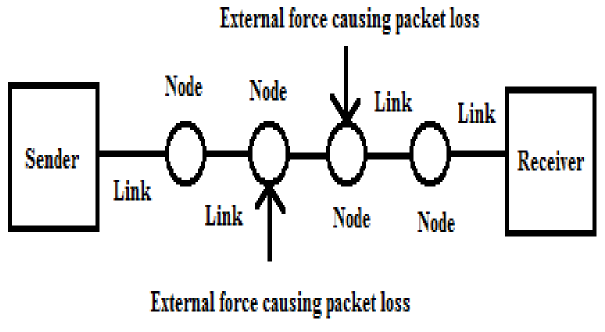

Figure 2. The network analog of the fluid flow model

Considering an infinite horizontal poorly conducting two-dimensional fluid layer with electro conducting rigid plates binding on both sides, segmented electrodes on the rigid plates located at y=0 and at y=h (as shown in Figure.1) having different electric potentials maintained at the boundaries given by $\varphi = \frac{v}{h}x$andφ=$\frac{v}{h}(x - x_0)$ as shown in Figure 1. Here (x, y) are rectangular horizontal coordinate system with x-axis horizontal and y-axis vertical as shown in Figure.1. The basic equations for the fluid in question are

Conservation of Mass:

$$\nabla.\vec{q} = 0 \tag{1}$$

Conservation of Momentum:

$$\frac{\partial \vec{q}}{\partial t} + (\vec{q}.\nabla)\vec{q} = \frac{-1}{\rho_0}\nabla p - \frac{\rho_e}{\rho_0}\vec{E} \tag{2}$$

Conservation of Electric Charges:

$$\frac{\partial \rho_e}{\partial t} + (\vec{q}.\nabla)\rho_e + \nabla.(\sigma\vec{E}) = 0 \tag{3}$$

Ohm's Law :

$\vec{J}$=σ \\\\\{$\vec{E}$ (4)

Here, the quantities used are electro hydrodynamic (EHD) approximations such as conductivity σ, of the liquid and magnetic field induced due to the motion. The approximations ensure that both the parameters are negligible. In continuation, the absence of an applied magnetic field makes the electric field $\vec{E}$, to be conservative. The Maxwell's Equations under these approximations are:

$$\text{Gauss Law :}\nabla.\vec{E} = \frac{\rho_e}{\varepsilon_o} \tag{5}$$

Faradays Law:

$\nabla \times \vec{E} = 0,$ \\" { widevec {E} =-∇ (6)

Here $\vec{E}$ is the sum of induced electric field due to variation of σ with stratification as explained earlier and applied electric field. Assuming two dimensional flow given by $\vec{q}$ = (u,v)$\vec{E}$ = $(E_x$,E$_y)$ and $\nabla = \frac{\partial}{\partial x}\hat{\imath} + \frac{\partial}{\partial y}\hat{\jmath}$ where (u, v) and (Ex, Ey) are velocity and electric fields in respective directions. Following the above approximations from equations (1) through (6) can be transformed into dimensionless expressions as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{7}$$

$$\frac{\mathrm{Du}}{\mathrm{Dt}} = \frac{-\partial p}{\partial x} - W_1\rho_e E_x \tag{8}$$

$$\frac{\mathrm{Dv}}{\mathrm{Dt}} = \frac{-\partial p}{\partial y} - W_1(\rho_e E_y) \tag{9}$$

$$\frac{\mathrm{D}\rho_e}{\mathrm{Dt}} + \frac{\partial \sigma}{\partial x}E_x + \frac{\partial \sigma}{\partial y}E_y = 0 \tag{10}$$

$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} = \rho_e \tag{11}$$

$$\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = 0 \tag{12}$$

where p the pressure, $\vec{J}$ the current density, ρ_e the density of electric charges, $W_1 = \frac{\varepsilon_0 v^2}{\rho_0 U^2 h^2}$ represents the ratio of electric energy to kinetic energy, R=$\frac{\varepsilon_o U}{\sigma_o h}$ the relaxation time represented as a dimensionless quantity,

$\frac{D}{\mathrm{Dt}} = \frac{\partial}{\partial t}$+u$\frac{\partial}{\partial x}$+v$\frac{\partial}{\partial y}$and $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$

The boundary conditions, in dimensionless form, are

(u,v) = 0aty=0and1 (13)

φ=xaty=0

φ=x − $x_0$aty=1 (14)

In a layered fluid medium such as a fibre network channel, the induced electric field becomes stratified. The current generated by this field actuated the flow of particles. If the electrical conductivity is constant, the charges will not be released that is $\rho_e = 0$. This implies that there is no induced electric field leading to no current and hence no motion. This shows that if σ is a constant the poorly conducting material will not function as a smart material.

Basic State

u=u$_b(y)$, σ=σ$_b(y)$, , $\vec{E}$=E$_b\hat{\jmath}$p=p$_b$(x,y) (15) where the suffix b denotes the basic state. Substituting (15) into (1) to (6) and then simplifying

$$\frac{\partial^2 \varphi_b}{\partial y^2} + \alpha \frac{\partial \varphi_b}{\partial y} = 0 \qquad (16)$$

where $\alpha = \alpha_h h$ is the volumetric coefficient of conductivity and $\rho_{eb} = \frac{-\partial^2 \varphi_b}{\partial y^2}$.

Solution of (16), using the boundary conditions (14), is

$$\varphi_b = x - \frac{x_0(1-e^{-\alpha y})}{(1-e^{-\alpha})} \qquad (17)$$

EHD Flow under an electromagnetic field's influence even though used in many application areas, is usually unstable. Thus this research explores the surface instability or linear stability of an EHD flow that can generate EHD stability where data is treated as charged particle and the fluid is the channel and the governing conditions for this work are presented by modified Orr-Sommerfeld equation.

IV. ANALYSIS

From, Figure 1, and the analogies obtained, the stability of the motion of a packet through the assumed network can be modeled as follows.

The linear stability of the basic state is superimposed on a series of minute symmetric disturbances for further analysis.

$$u = u_b + u',\ v = v',\ p = p_b + p',\ \vec{E} = E_b j + \{E', \rho_e \rho_{eb} + \rho e' \qquad (18)$$

Where the derivatives are the infinitesimally small disturbances from the basic state. Using (18) in eqns. (7) to (12) and linearizing them by approximating the higher terms to 0 as they are negligible, they become,

$$\frac{\partial u}{\partial t} + u_b \frac{\partial u}{\partial x} + v \frac{\partial u_b}{\partial x} = \frac{-\partial p}{\partial x} - W_1 \rho_{e_b} E_x \qquad (19)$$

$$\frac{\partial v}{\partial t} + u_b \frac{\partial v}{\partial x} = \frac{-\partial p}{\partial y} - W_1 \left(\rho_{e_b} E_y + \rho_e E_{b_y}\right) \qquad (20)$$

The stream function ψ satisfying (7) is defined as

$$u = \frac{\partial \psi}{\partial y},\ v = -\frac{\partial \psi}{\partial x} \qquad (21)$$

When the pressure parameter between (12) and (13) is eliminated and (14) is applied with normal mode solution of the form

$$f'(x,y,t) = f(y) e^{il(x-Ct)} \qquad (26)$$

the stability equation becomes

$$-(D^2 - l^2)\psi + \frac{D^2 u_b \psi}{(u_b - C)} - \frac{W_1 x_0 (D^2 - l^2)\varphi}{(u_b - C)} = 0 \qquad (27)$$

Similarly, continuity of charges equation (10) can be expressed as

$$[il(u_b - C)](D^2 - l^2)\varphi = il\alpha^2 x_0 \psi \qquad (28)$$

Substituting $(D^2 - l^2)\varphi$ from (17) into (16) and after simplification

$$D^2\psi - l^2\psi - \frac{D^2 u_b \psi}{(u_b - C)} - \frac{W_1 x_0^2 \alpha^2 \psi}{(u_b - C)^2} = 0 \qquad (29)$$

Final equation

$$-(D^2 - l^2)\psi + \frac{D^2 u_b \psi}{(u_b - C)} - \frac{W_1 x_0 (D^2 - l^2)\varphi}{(u_b - C)} = 0 \qquad (30)$$

Then (28) takes the form

$$[il(u_b - C)](D^2 - l^2)\varphi = il\alpha^2 x_0 \psi \qquad (31)$$

Substituting $(D^2 - l^2)\varphi$ and after simplification $D^2\psi - l^2\psi - \frac{D^2 u_b \psi}{(u_b - C)} - \frac{W_1 x_0^2 \alpha^2 \psi}{(u_b - C)^2} = 0$ (32)

This is a modified form of Rayleigh Equation.

Where

$$D = \frac{\partial}{\partial y}$$

l is the wave number

ψ is stream function

U for velocity, u_b is the basic state

C = n / l, the wave velocity, n is the frequency,

$W_1 = \frac{\varepsilon_0 v^2}{\rho_0 U^2 h^2}$ the Electric Number which represents physically the ratio of electric energy to kinetic energy,

scales h for length, U for velocity, $\rho_0 U^2$ for pressure, $\frac{\varepsilon_0 V}{h^2}$ for charge density in the fluid ρ_e , V for potential, $\frac{V}{h}$ for electric field, σ_o for conductivity, ρ_0 the density of fluid, ε_0 the dielectric constant

with the segmented electrodes as shown in Figure 1, having different electric potentials $\varphi = \frac{v}{h} x$ and $\varphi = \frac{v}{h}(x - x_0)$ maintained at these boundaries.

The boundary conditions, in dimensionless form, are

$(u, v) = 0$ at $y = 0$ and 1

$\varphi = x$ at $y = 0$

$\varphi = x - x_0$ at $y = 1$

From the above equations, it is clear that the energy required to nullify the effects of failures at any given link or a node has an exponential trend. This indicates that a network can be modeled as an EHD fluid flow under adverse conditions and analyzed using the above expressions. The equation is then tested for different number of failures, i.e. increasing number of orthogonal energy sources to divert the particle (packet) flow. The data transferred and failures induced to mimic the network node failures and link failures are plotted. The same is explained in the next section.

V. RESULTS AND DISCUSSION

The energy required to overcome the packet losses is obtained in milliWatts hour. The same is plotted against the number failures. The obtained graph is as shown in Figure 3.

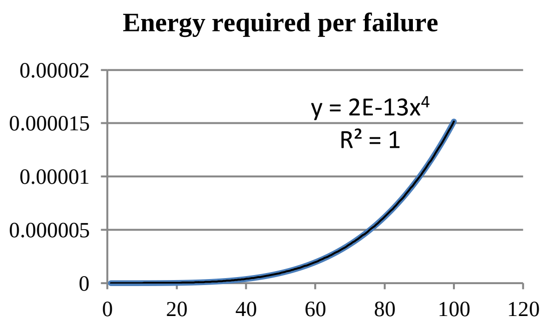

Figure 3. The energy required in mWh per failure

From the graph it can be observed that, the energy required increases as a 10 to the -4th power of the number of failures and if logarithmically plotted, the graph would appear linear. This indicates that, any network susceptible to multiple failures requires a higher energy source at each repeater and the errors become untenable to handle once the required energy reaches 0.001 mWh.

VI. CONCLUSION

In this paper, a method of conducting an energy analysis for a computer network using the fluid flow model with an obstructive medium has been presented. The method presents a stable closed form equation for estimating the energy required to handle multiple errors in a given network irrespective ofg the size of the network in terms of spanning distance, number of nodes etc. Since, such an analysis is not done prior to this attempt, a comparative conclusion cannot be drawn for this work. However, the method proposed shows promise as a tool for network modeling in the future. It can further be enhanced as a tool for dynamic network simulation. Also, the model can be extended from individual nodes to network of networks and used as a global model where failures are prevalent.

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