**Study on Viral Aerosol Transmission and Detection**

**Abstract:-**

In this research, we suggest using the mechanism of disease dissemination in the atmosphere as an engineering problem. Among the viral modes, aerosol transmission is the most important modes of transmission that don't involve physical contact, when long-distance virus-laden droplets are carried by airflows. In this paper, we examine how these droplets are transported as an uncontrollable molecular communication issue over the source of transmission, while a strong receiver can be created with the use of biosensors. In light of this, we provide a comprehensive construct a system model and obtain a comprehensive mathematical model for the channel of transmission under specific limitations and boundaries circumstances. The system response is derived for both continuous sources like respiration and jet or spontaneous sources like sneezing and coughing. We assumed a receiver design made up of a silicon nanowire field-effect transistor and an air sampler in addition to the transmitter and channel. Next, we create a detection problem to optimize the decision rule for likelihood and reduce the likelihood of the corresponding missed detection. Lastly, we provide a number of numerical findings to show the effects of factors that impact performance and simply justify the feasibility of the proposed setup in related applications.

**Index Terms**— Communication through breath, aerosol transmission, virus detection, molecular communication, nanonetworks, channel modeling, molecular receiver, advection diffusion channel.

1. **INTRODUCTION:**

An growing field of study that focuses on the communication processes involving biological entities is called molecular communication (MC). MC employs molecules as signaling sources, as opposed to traditional wireless communication, which encodes and transmits electromagnetic signals to exchange information. Only recently has this phenomena drawn attention from the scientific world, despite the fact that it is a communication mechanism that most living things inherently possess. Recent developments in nanotechnology and the introduction of nanoscale biosensors or nano technologies are credited with generating this interest and advancing the field's research[1]. The small size, limited energy supplies, memory, and processing capability of the current nanotechnology limit their possibilities. Many nanotechnology must thus interact in order to carry out complex functions, and this is where the idea of MC is crucial. Although current electromagnetic and optical technologies are unable to create links between nanotechnology, MC offers this connection, enabling the formation of a cooperative network of nanotechnology[2]. The construction of artificial networks that can mimic biological networks both within and outside the human body is made possible by research in this field. This will not only aid in comprehending how intricate biological systems like the brain function, but it will also aid in the treatment of a number of illnesses and conditions brought on by malfunctioning internal communication channels [3]. Therefore, it is anticipated that these developments will be crucial for manufacturing, biomedical, and ecological uses [1]. Neural network modeling, the creation of ICT-inspired therapies [3], and intelligent medication delivery are a few newly investigated biomedical applications[4]. In addition to biological applications, MC has been examined from a communications perspective, which emphasizes coding principle, assessment of modulation programs, and the design of effective receivers [5]. It should be mentioned that because of the complexity of the process, the current solutions for traditional communication cannot be easily transferred to MC setups. The problems with MC include non-stationary signal-dependent noise, range restrictions that let nanotechnology communicate over short distances (less than a few micrometers), significant propagation delays, problems with molecule reactivity that lead to high loss rates, memory limitations, power constraints, and connection between bio-nanotechnology and nanotechnology [1]. These difficulties greatly influence the present and future paths of this field's research. Additionally, the ability of these nanoscale sensing structures to interact with living things like bacteria has created a number of new study opportunities. For example, bacterial compounds operate as messengers for communication between bacterial colonies, where receptor bacteria emit light in response to molecules they receive, rather than artificially generated molecules and chemicals[6].

In addition to micro and macro-level applications, researchers have also put efforts in understanding and replicating the existing biological processes/systems and interfacing with them. In this work, we propose a new dimension in MC that focuses on the spread of infections and diseases via aerosols. Viral aerosols are virus-laden droplets that are suspended in air for prolonged periods of time [7]. These particles are dispersed in the surrounding because of molecular diffusion and are carried away by wind and this transport is called aerosol transmission. This transmission of viruses leads to disease spread on a very large scale with a massive impact on human population. It has been shown that aerosol transmission is an important mode of transmission for several viruses such as influeza A virus [8], severe acute respiratory syndrome (SARS) virus [9], lyssavirus [10], rabies [11] and many other pandemics. Unlike the traditional research in MC, for this particular context the message-bearing entities can not be modulated and the message can not be embedded as desired. However, we believe that the virus-laden exhaled air from an infected person can serve as a source of useful information and we need to design our receiver in order to retrieve this information. The significance of this proposed research dimension is even more highlighted in high human population scenarios. It is common to observe Mass gatherings when people get together for sports, recreational, social or religious activities. During these gatherings, the large movement of people from different regions poses high risk of disease transmission and transport of emerging and reemerging diseases to the gathering place. The increase in likelihood of disease transmission during Mass gatherings is reported in [12]–[15]. The detection system proposed in this work can help deal with this problem. If an efficient detection setup is deployed at the entry point of gathering events like railways stations and airports and the likely hosts of diseases and endemics are spotted and treated before they become part of the gathering, the spread of diseases can be significantly prevented. Moreover, if accurate models for virus transport and its dynamics can be established, a blind localization problem can be formulated that can prove helpful in identification of disease sources. Thus, in order to be able take any preventive measures against disease spread, it is essential to characterize and analyze the dynamics of virus transport as has been done in this work.

**II SYSTEM OVERVIEW**

The fundamental design of a single source viral aerosol transmission system is briefly explained in this section. There are three main parts to the suggested system. The first is the diseased person who spreads the infection; throughout the rest of the paper, this person is called the transmitter. The second element is the pathway via which the virus spreads through aerosols. It is possible to expose the gearbox to airflow, or artificial wind. The third element is the receiver side, which seeks to obtain data regarding the disease and/or virus.

The goal of this paper is to recover viral information from aerosols expelled from infected persons' respiratory tracts, as shown in Figure 1. In order to propel the particles towards the detector, the experiment is conducted indoors where artificial airflow with a predetermined velocity can be applied. It should be mentioned that the experimental setup being considered is extremely similar to a real-world scenario in which virus droplets spread due to wind. Therefore, the models developed in this work can be used for both qualitative and quantitative investigation of infection transmission in addition to bio-monitoring applications.

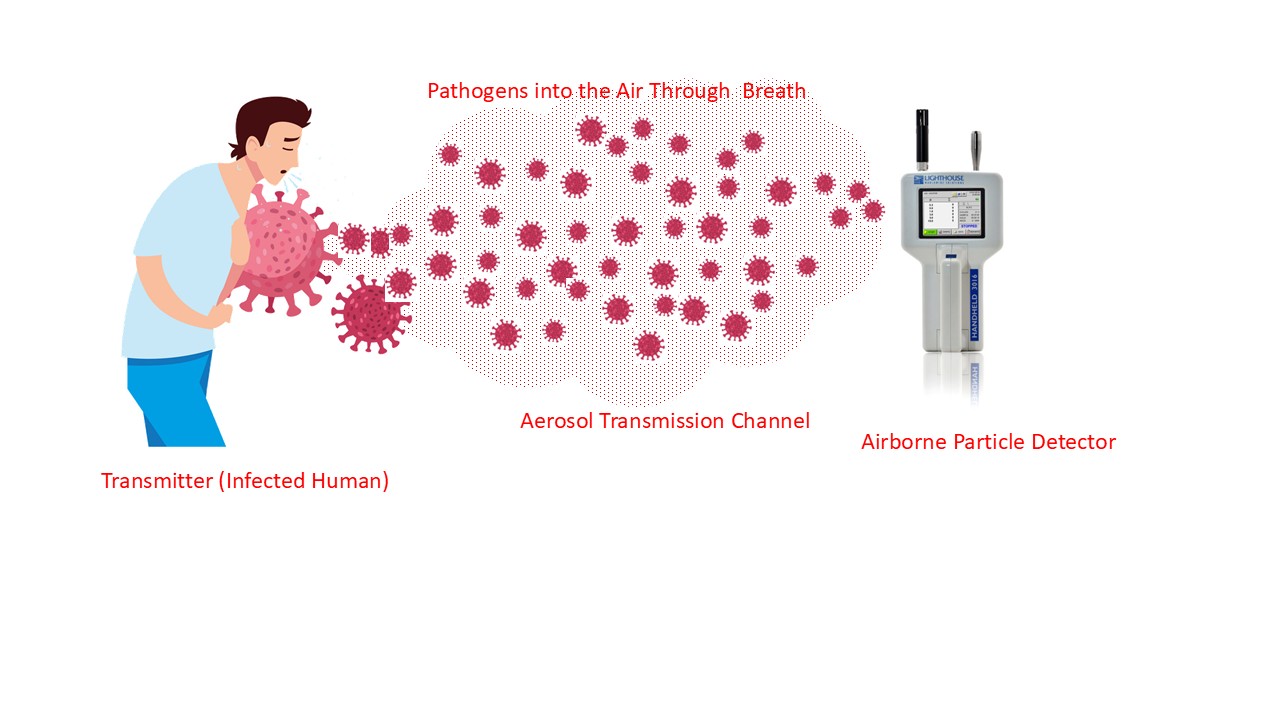


Figure 1. Aerosol transmission Description

**III SYSTEM MODELING**

This section's goal is to examine each system block in Figure2 independently. The transmitter is the first component of the system, followed by the physical channel with additive noise and the detector. The full mathematical modeling of the various system components is presented in the ensuing subsections.

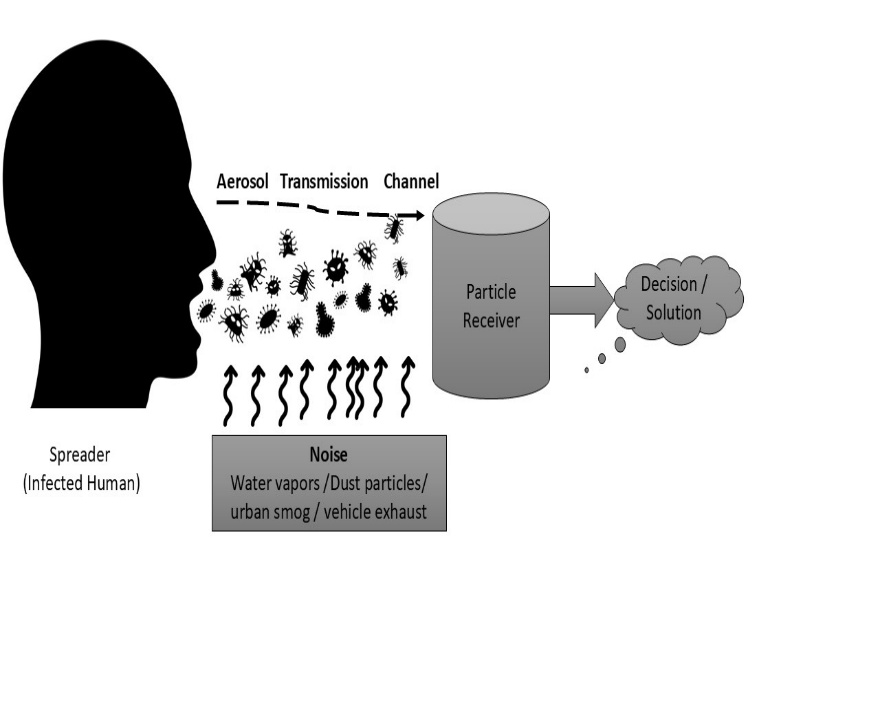


Figure 2 :Block Diagram

**A.** **Spreader**: It is assumed that the infected person's breath spreads microorganisms into the atmosphere. An adult's normal breathing rate is 12–16 breaths per minute [24], meaning that each breath should take no more than 4.98 seconds. Please be aware that chemical signaling transmission is much slower than wireless communication, and it may take several minutes for the signal to reach a receiver a few meters away. Therefore, the transmission procedure guarantees that the experiment's time scale is on the order of minutes. The differences in the emission process caused by exhalation can be averaged out and the process can be roughly described as a continuous and constant emission process because the time within breaths (or exhalation time specifically) is too short in comparison to the experiment's duration, which is of the order of several minutes. Although the emission rate may fluctuate over time, we anticipate that the average rate will remain consistent for the duration of the experiment (a few minutes at most). Finding a deterministic or stochastic model that can explain these variations in the literature is challenging, despite the fact that it is beneficial if the emission rate variations can be included in the system design. The majority of empirical research on this topic is based on gathering breath samples that range in duration from a few minutes (about 30 minutes) to hours and documenting the cumulative effect. It is unclear if the existing technology can assess the fluctuations in the emission rate per second for the brief time frames. As a result, we represent the input signal as a continuous process with a constant average emission rate, or Q g/sec.

Breathing is a common source of impulsive jets, but they cannot be guaranteed to be constant. The duration of an experiment or the application's temporal features are crucial for simulating the input signal. The steady state response is adequate for certain applications, like understanding disease spread or detection in specific settings. Transitory response is necessary for applications requiring fine-grained data for decision-making. This section covers transient analysis for jet sources, breathing, and steady state response, considering both time and space dynamics. The input is represented differently for transient analysis. A single cough or sneeze is regarded as an instantaneous jet source that releases As aerosols into the atmosphere. If a person standing at position [0,0,H] in any space with a height of around H sneezes or coughs at time t = 0, the source is modeled as [18],

Ss = Asδ(x)δ(y)δ(z −H)δ(t).

Where As is Aerosol of Sneezing person.

In a similar manner, the individual constantly releases aerosols with a specific flow rate Ab while breathing. The source is modelled as follows if the individual entered the room or experimental setting at time t = 0 and then stood at the same spot [0,0,H] again:

Sb = Abδ(x)δ(y)δ(z −H)u(t).

Where Ab is Aerosol of breathing person.

The definition of input signal should cover both continuous and jet sources because a person who sneezes is also breathing. Therefore, we define the final input signal as follows, assuming that both of these emissions are independent of one another:

St=SS+Sb

If there are several persons in the room at different places, their independence from one another means that the final input signal is simply the sum of all of their emissions. The size of the aerosol droplets influences the communication performance in addition to the emission rate.

**B. Particle Receiver**: We suggest a detection method that could be used to differentiate between an infected and healthy individual. The receiver serves as an absorbing surface that absorbs the majority of the pathogen-laden droplets after the infected person has discharged a specific quantity of pathogens into the atmosphere and they have crossed the molecular channel. The architecture of particle receiver is shown in Figure 3. The details of three major blocks are presented below.

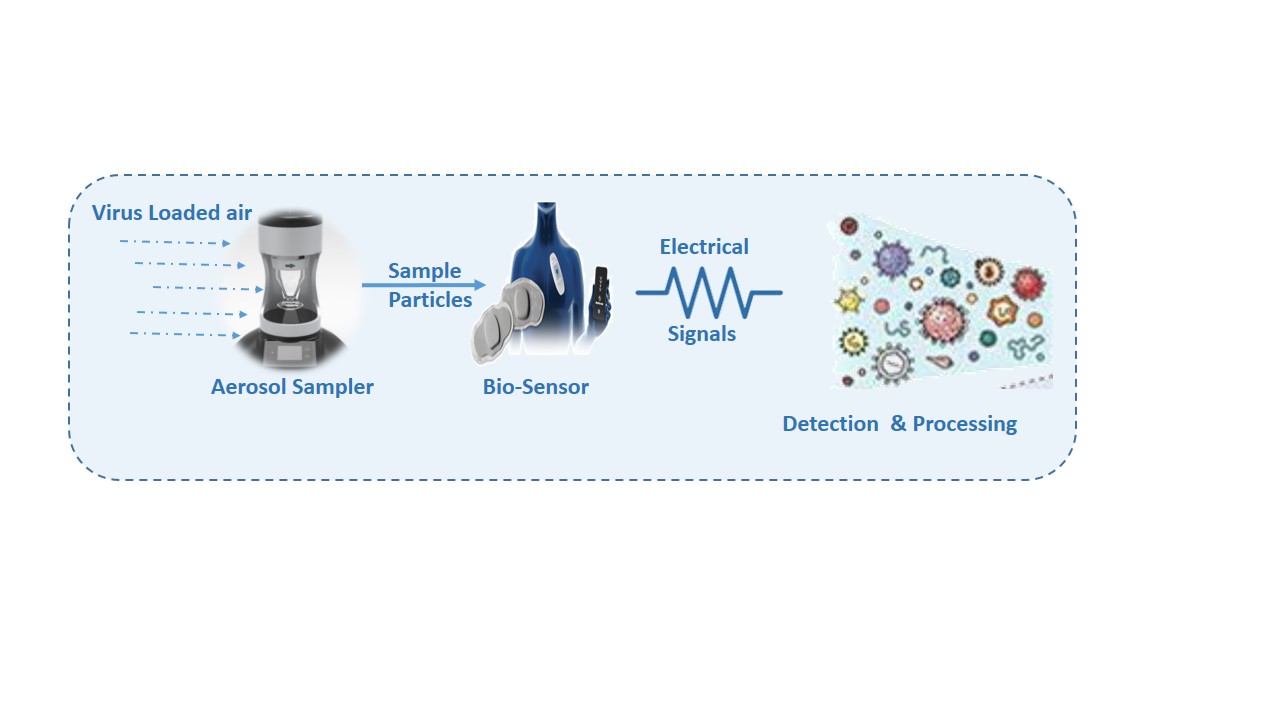


Figure 3: Architecture of Particle Receiver

* **Aerosol Sampler**: A number of methods for gathering suspended air particles have been developed. The front end of our receiver, known as the aerosol tester, regulates the air sampling rate. The tester suggested in this receiver architecture is based on the electrostatic precipitation concept, which is not only commercially available but also enables sampling of particles as small as 2–100 nm, despite the existence of various alternative methodologies. Since the diameter of bacteria and viruses can generally be of the order of nanometers and droplet sizes are of the scale of a few micrometers, the sampler's sensitivity in terms of sampling nano-sized particles is quite considerable. Figure 4 shows the electrostatic air sampler's construction. The ionizer and the charged electrode are the sampler's two primary parts. After being repelled by the outer negatively charged boundary, the ionizer creates a negative charge on the air particles that move on to the next chamber and gather on the positively charged electrode. The efficiency of the sampler's collection is used to measure its performance. Commercial electrostatic aerosol samplers can achieve collection efficiencies of 80 to 90%, as reported in [16]. For the remainder of the work, we use ξ to represent sampler efficiency.

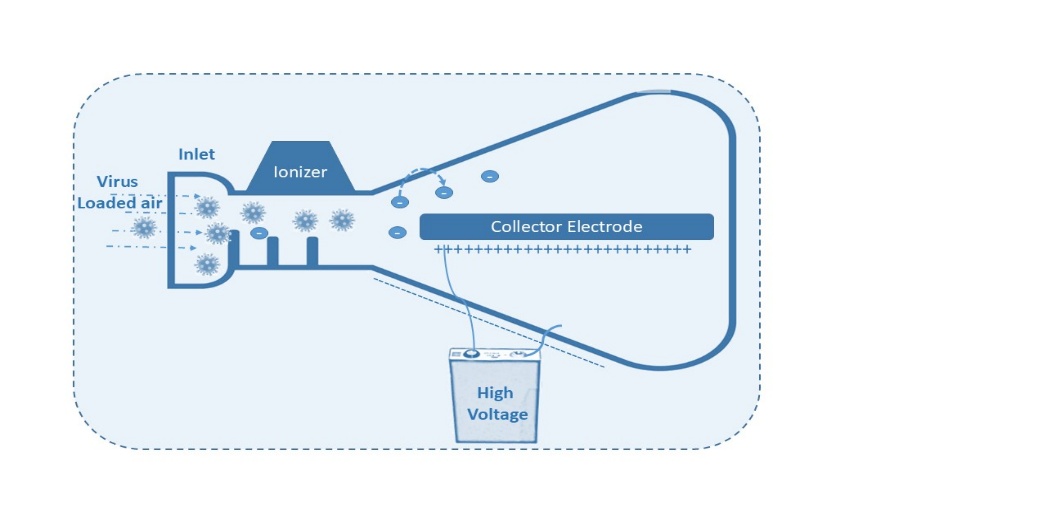


Figure 4: The Electrostatic Air Sampler's Construction