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The opportunistic transmission of wireless worms between mobile devices

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ABSTRACT

The ubiquity of portable wireless-enabled computing and communications devices has stimulated the emergence of malicious codes (wireless worms) that are capable of spreading between spatially proximal devices. The potential exists for worms to be opportunistically transmitted between devices as they move around, so human mobility patterns will have an impact on epidemic spread. The scenario we address in this paper is proximity attacks from fleetingly in-contact wireless devices with short-range communication range, such as Bluetooth-enabled smart phones.

An individual-based model of mobile devices is introduced and the effect of population characteristics and device behaviour on the outbreak dynamics is investigated. The model uses straight-line motion to achieve population, though it is recognised that this is a highly simplified representation of human mobility patterns. We show that the contact rate can be derived from the underlying mobility model and, through extensive simulation, that mass-action epidemic models remain applicable to worm spreading in the low density regime studied here. The model gives useful analytical expressions against which more refined simulations of worm spread can be developed and tested.

1. Introduction

The modern world has become increasingly mobile. As a result, traditional ways of connecting computing devices to the Internet (and to each other) via physical cables are proving inadequate. Recent years have seen the widespread adoption of portable computing devices which are equipped with a short-range wireless technology such as WiFi [1] or Bluetooth [2]. Wireless connectivity is greatly advantageous as it poses little restriction on users' mobility and allows a great deal of flexibility. At the same time the ability to wirelessly connect to the Internet (and other devices), and to transfer data on the move, is opening opportunities for hackers to exploit such features for launching new and previously unexplored security attacks on computer and communication networks [3–6].

Indeed, the last few years have seen the emergence of a new class of potentially destructive computer viruses that exploit such wireless capabilities in order to spread themselves between nearby devices, often without any active user involvement.

One important feature of these new types of computer worms is that they do not require Internet connectivity for their propagation and therefore can spread without being detected by existing security systems. Another important feature is that, since they target portable devices, they can exploit the mobility of users for their spreading, in a way which shows interesting analogies with the spread of biological infectious diseases in a human population.

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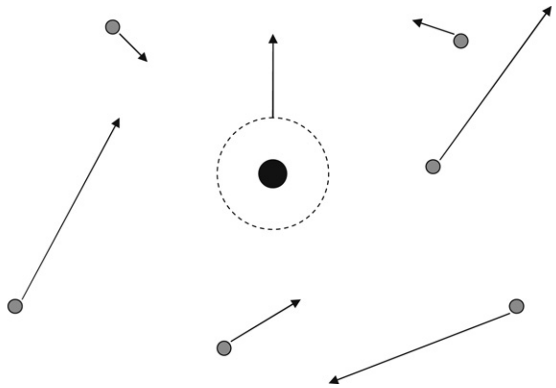

Fig. 1. A specified individual is located at the centre of the large (dashed) circle, radius R, and is moving through the domain in a straight line. Other individuals move across the domain in straight lines; velocity vectors are uniformly distributed in azimuth. When an individual passes within a distance R of the specified individual contact is made with probability p. All the particles are treated as point-like.

The spread of such wireless epidemics [4,5] among WiFi-enabled computers placed at fixed locations has been investigated very recently [5]. These studies have revealed that the patterns of epidemic spreading in such networks are greatly different from the much studied epidemics in wired networks, and are strongly influenced by the spatial nature of these networks and the specifics of wireless communication.

The above static description is relevant in a situation where the underlying wireless contact network along which the epidemic spread is either connected or has a very large connected component. However, when device density is low or the infected devices have a very limited communication range (e.g. in the case of Bluetooth-enabled mobile phones [3]), at any time instant the underlying wireless contact network will be fragmented into many isolated clusters, rendering network propagation ineffective. In such situations, we expect worm spreading to take place in an opportunistic manner where infected devices exploit the mobility of the users to transmit the worm to other devices to which they make a fleeting contact. The temporal patterns of such contacts and their duration depend on the underlying movement patterns of user mobility [7]. Therefore, in order to model the opportunistic spread of wireless worms between portable devices it will be necessary to develop a class of epidemic models that reflect the specific characteristics of human mobility, patterns of population aggregation and the wireless nature of worm transmission between devices [8]. Such models will inform the construction of mitigation strategies aimed at containing and eliminating future worm epidemics.

Here we present a model for the epidemic dynamics of a worm outbreak in a mobile spatially distributed population of wireless-enabled devices. Whilst worm spreading in fixed and ad-hoc networks has begun to be investigated in some detail [5,6], the opportunistic spread between spatially proximal mobile devices has received less attention. The model elaborated below is constructed so as to reflect device mobility as well as the transmission characteristics of the worm. The transmission characteristics are determined by the wireless technology that is used for inter-device communication. Specifically, we show that in the low density regime where there is no spatial correlation of any initially infected devices, worm epidemics can be described by standard mass-action mixing models, and that the contact rate for those models can be derived from consideration of the kinetic model.

The model framework presented here provides a number of analytic results, which are verified via individual-based simulations. These results are important in quantifying the impact of device mobility on the spreading of worms and other types of viruses in mobile wireless networks. We do not specifically address issues relating to attack mechanisms; rather, the emphasis here is on dynamics of the spreading process. However such issues are discussed in Refs. [3,6]. Our results are also relevant to the analysis of novel delay-tolerant communication protocols which are being intensively researched for information dissemination and routing in intermittently connected wireless networks [9].

2. Opportunistic transmission model in a mobile population

2.1. Contact rate calculation

It is necessary to first calculate the contact rate between individuals in a mobile spatially distributed population. To do this, the motion-dependent contact rate for a given individual (denoted i) with others in the population is calculated [10, 11]. The contact process model consists of a population of individuals that are randomly and uniformly distributed over a two-dimensional domain with a density ρ. As illustrated in Fig. 1 each individual moves independently of the others with a constant straight-line velocity $\vec{v}$, with their direction vectors distributed uniformly in azimuth in the plane. Human mobility patterns are more complex than straight-line motion, but this is a first approximation to permit the first steps to a more realistic model. A specified individual, i, is introduced and moves through the domain with velocity $\vec{v_i}$. If one of the individuals passes within a radius R of the specified individual i then, by definition, a contact has been made. Here we